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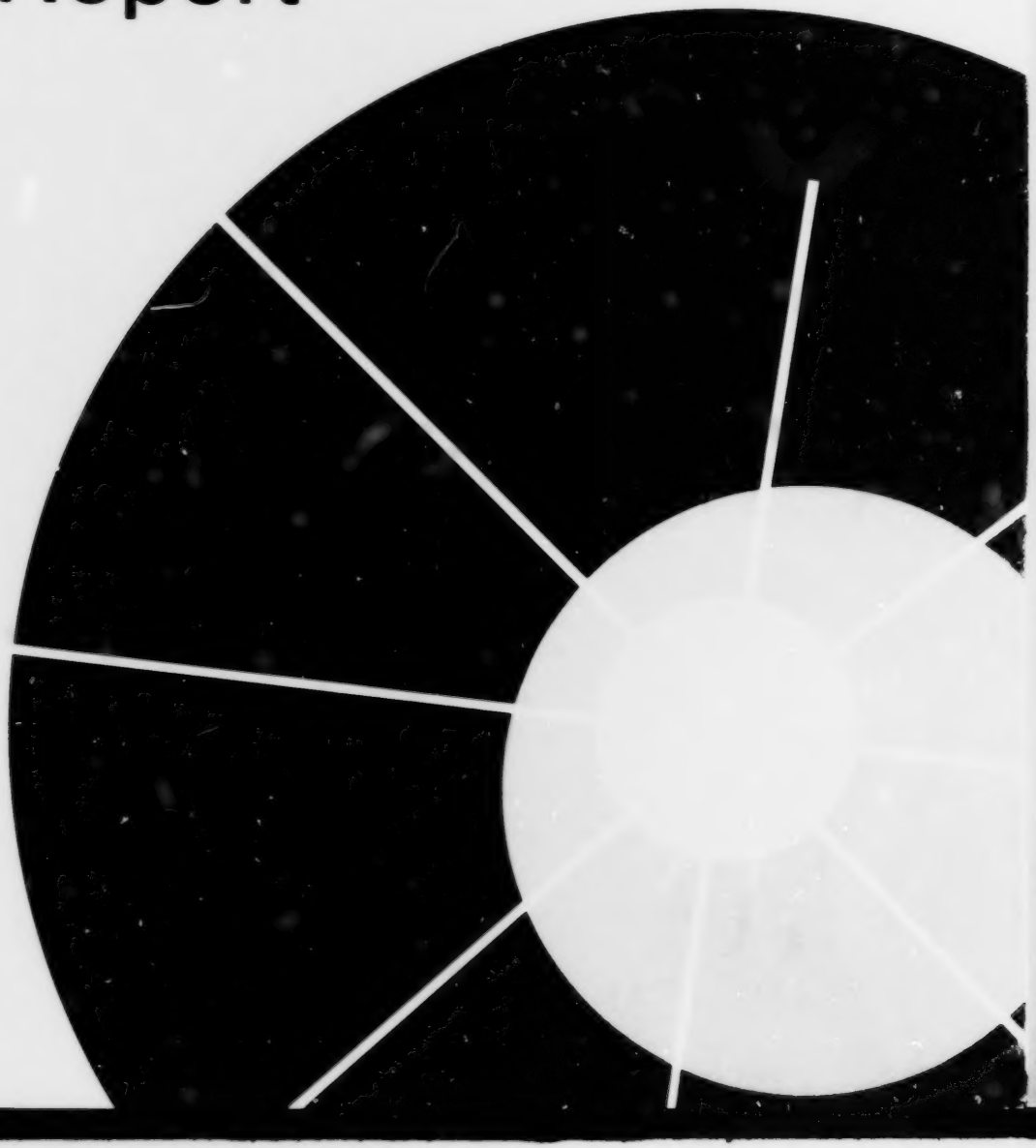
Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report



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CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

— To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;

— To create employment in new or existing industries;

— To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

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Solar-Heated Garage/Workshop

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

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And Supported By

Saskatchewan Energy and Mines
and
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Miscellaneous
Report FP-12

A SOLAR HEATED WORKSHOP-GARAGE

March 1, 1983

L.A. Ingham-P.Eng.

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1. INTRODUCTION

In January of 1980 a decision was made to build a combination workshop-garage of about 600 square feet floor area with dimensions of 20 ft. by 30 ft. with 8 ft. walls. Construction was to be wood frame, using 2 by 4 studs, standard pitch roof, and concrete floor. Heat would be provided by an oil fired space heater.

The building was to be used intermittently and often for only short periods of time. There was some concern over heat-up time which would be required in cold weather and also concern over not being able to store freezable materials in the building. Both problems could be solved by using continuous heating, but this would not be cost effective because of the intermittent use.

Solar heating was then considered as an energy source, combined with high levels of insulation for energy retention. Although the intitial cost would increase, part of the heat energy would be "free", allowing the interior temperature to be maintained above freezing, at a reasonable energy cost. Heat up time would consequently be reduced to acceptable values. A back-up heating system would of course be required. It was anticipated that the high levels of insulation would be useful in keeping the interior temperature at a comfortable level during the hot summer days.

A decision was made to use the building as a research project as well, to provide data on solar heating, high insulation levels, building sealing, and related topics.

Construction of the building was begun in June of 1980 and application was made to the Saskatchewan Department of Mineral Resources for joint Federal-Provincial financial assistance under the Renewables-Conservation Demonstration Program. A grant was provided to assist in the materials cost. Assistance was also given in the providing of monitoring equipment.

This report consists of two main parts. The first deals with theoretical considerations regarding the use of solar energy, building insulation, vapour barriers, and sealing of buildings. The second part considers the application of these principles to the test building, along with monitoring results and conclusions.

This report uses imperial measuring units but provides conversion factors to S.I. units in the Appendix.

2. SOLAR ENERGY AVAILABLE

The amount of solar energy available at a height of 90 statute miles is about 442 B.T.U./HR./FT.^{2} In a plane perpendicular to the sun's rays. This figure is relatively constant over an entire year. 442 B.T.U./HR. converts to 111 KCAL/HR. or 130 watts. If one considers a house with 1200 FT^2 of roof area, capable of capturing this energy, it is equivalent to 530,400 B.T.U./HR. or 156 KW. which is about five to ten times the average homes energy consumption rate. There are three reasons however why these calculated energy absorbtion rates are not possible:

1. It is not practical with present technology to use the entire roof area for solar energy collection.

2. The amount of energy available at the earth's surface is much less than that available at high altitude.

3. Energy collection systems are not 100% efficient.

At the surface of the earth the energy available when the sun is directly overhead is approximately 320 B.T.U./HR./FT^2 through a plane perpendicular to the sun's rays. The amount is slightly less in the summer months due to higher moisture levels in the atmosphere. A more realistic figure to use is the amount available at noon on December 22nd, at a latitude of 52 degrees north, which is 230 B.T.U./HR./FT^2, through a plane perpendicular to the sun's rays. This figure converts to 68 WATTS/FT^2. One must consider however that this is the amount of energy available during the best hour of the day and reduces to zero from sunset to sunrise. Table One shows the amount of energy available on December 21 and January 21 Vs time of day. The data is for a latitude of 52 degrees north and applies to a south facing wall at the angles as indicated. It is interesting to note that on December 21, 60% of the total daily energy is received during the middle three hours of the day. Table Two shows the average daily energy available for each month of the year for a south facing surface at three different angles for a latitude of 52 degrees north.

Tables One and Two were based on clear sky conditions, and were therefore indicating maximum values. Table Three shows maximum energy values for each month and also actual average values based on real weather conditions. The data is again for Latitude 52 degrees north. The partial year totals at the bottom of the table were calculated because collecting surfaces are normally shaded from the sun during the warm summer months.

Graph Number 4 shows the relationship between energy levels and wavelength. The Graph is an average since the exact relationship is constantly changing due to fluctuations in atmospheric conditions and in ionospheric conditions. It is interesting to note that over 50% of the energy is not in the visable range.

3. HEAT LOSS THEORY

Heat may be transferred by any combination of the following Methods:

1. Radiation
2. Conduction
3. Convection Currents

Radiation

The heat energy radiated by a body depends upon its absolute temperature and the nature of its surface, in the following way:

$$q = E\sigma T^4$$

Where q is heat flow in B.T.U./HR.

E is the emissive power of the surface

σ is a constant (Stefan-Boltzmann constant)

T is the absolute temperature of the surface

The emissive power is a function of the wavelength of the radiation and thus to get the total heat flow across a band of wavelengths it is necessary to integrate.

As well as radiating heat energy all objects receive radiated energy from their surroundings according to the following formula:

$$q = \alpha T^4 \sigma$$

Where q is heat flow in B.T.U./HR.

α is absorbtivity of the surface

σ is the Stefan Boltzmann constant

T is the absolute temperature of the surroundings

The absorbtivity of the surface is also a function of the wavelength of the radiation striking the surface and integration must be used to get totals.

Table 5 shows the average value of the absorbtivity of some common surfaces for solar energy. Notice that flat black paint has a high absorbtivity for solar energy.

3. HEAT LOSS THEORY cont.

For most materials E and α are the same which means that a good absorber is also a good emitter. "Selective" coatings however have been developed which are better absorbers than they are emitters. Such coatings are excellent for the collection of solar energy. They are however costly and must be applied by special techniques.

Although the absorbtivity and emissivity are the same for most materials, some materials (flat black paints) get much warmer than others (white paints) when exposed to solar radiation. The greater temperature rise is due to the sun's temperature being much higher than the objects temperature, resulting in more energy being received than emitted. The following example illustrates this phenomenon:

Surface	α	E	Energy Received	Energy Radiated	Net Gain
Black	.97	.97	1000	200	800
White	.35	.35	360	72	288

The net gain by radiation will raise the temperature of the surface until its temperature is sufficient so that its loss by radiation plus its loss to the surrounding air by conduction and convection balance the heat gain from the sun.

The wavelength of the energy radiated by an object is affected by its temperature, with the wavelength being smaller at higher temperatures. This behavior explains what is referred to as the "Greenhouse effect". Solar energy penetrates the clear atmosphere and window glass with little absorbtion. When the radiation strikes an object inside the building it is absorbed, resulting in a temperature rise of the object. The object then emitts radient energy, but since its temeprature is much lower than the sun's temperature, the average wavelength of its radiation is much longer than the wavelength of the solar energy. The object's radiation is consequently reflected by the window glass, and thus trapped in the building.

Since the temperature of the surface of a house is relatively low, the heat loss by radiation is small and usually not considered in the calculation of heat loss. In solar heat collection devices however the temperatures reach values such that radiation heat losses must be considered.

An interesting phenomenon, caused by radiation heat loss, occurs in air temperatures near freezing. Fruit crops have been known to suffer frost damage when the air temperature had remained above the freezing point. On a clear night space has a "Radiation" temperature of approximately -50°F. Thus, the object radiates more energy than it receives, and its temperature drops far enough below air temperature so that the conductive heat gain from the air balances the net heat loss by radiation. The result can be frost damage.

3. HEAT LOSS THEORY Cont.

Conduction

Heat loss by conduction accounts for the main part of the heat loss from buildings. Fortunately it is also the easiest type of heat loss to analyse. As with other cause and effect phenomenon the following relationship applies:

$$\text{Effect} = \frac{\text{cause}}{\text{resistance to effect}}$$

In heat units

$$q = \frac{\Delta T}{R}$$

$$q = \text{B.T.U./HR.FT.}^2$$

$$\Delta T = {}^{\circ}\text{F}$$

$$R = \frac{{}^{\circ}\text{F HR. FT.}^2}{\text{B.T.U.}}$$

Note that the R must be the total resistance across which the ΔT occurs. Table 6 shows the resistance of some common materials. Note that some thermal resistances are given per inch while some are given for the thickness of the given type of material. The following items from Table 6 are worth noting:

1. Still air is an excellent insulator
2. Concrete is a poor insulator
3. Soil is a poor insulator
4. There is an air film resistance at the surface of materials.

Convection

Heat loss by convection currents requires an air space free of insulation. Such spaces occur in the region between window panes, and the width of these spaces determines the amount of convection current present. This method of heat loss will be discussed in more detail in a later section on window design.

4. VAPOUR BARRIERS

Vapour barriers serve two functions: A) they prevent the diffusion of moisture from the interior of the building into the wall and attic space, b) they prevent air movement through the walls and ceiling.

During the heating season the relative humidity of the air inside a house is usually from 25% to 40%. Using A.R.H. value of 30% and an indoor air temperature of 70°F, one finds that the dew point temperature is approximately 54°F. If the inside air, having its original moisture content, is cooled to 54°F, then condensation will occur.

If there is no vapour barrier on the inside of a wall then moisture will diffuse into the wall, giving the same amount of water vapour per cubic foot of air in the wall space as there is present in the inside air. At some point in the wall space (toward the outside portion) the dew point temperature will occur and condensation will take place. This will result in staining of the outer wall surface, and possible rot within the wall structure. Graph 7 illustrates the dry bulb air temperature, and the dew point temperature within a typical wall space, and shows the effect of the vapour barrier. Vapour barriers must be installed at, or near, the warm side of the wall. To be effective they should be continous and well sealed at windows, electrical plugs, or other openings. Some present day construction techniques put the vapour barrier on the inner surface of the studs, then add 2" to 3" insulation, then the plasterboard. The wiring is done in the space between the vapour barrier and the plasterboard. The vapour barrier should not be more than one third of the way from the inside wall surface to the outside surface, as determined by R value, not by actual distance.

5. Air Infiltration

In Pre 1975 houses infiltration usually accounts for approximately 20% to 30% of the total heat loss. As houses are built with more insulation the percent of heat loss due to infiltration increases unless sealing is also improved. The following chart shows a typical heat loss breakdown for a pre 1975 house.

ITEM	HEAT LOSS(B.T.U/HR)	% OF TOTAL
Walls	4500	10 to 20
Ceiling	3750	10 to 15
Doors and windows	6000	20%
Basement	7500	25%
Infiltration	8250	27.5%
	30000	100

The effect of infiltration can be illustrated by the following: assume the unsealed area is 1/2 square foot. (192 feet of 1/32" width cracks). Assume a wind velocity of 15 M.P.H., and also that the velocity through the openings is 2 M.P.H. The volume of air will be 1/2 x 2 x 5280 = 5280 cubic feet. The density of air at room temperature is about .075 LBS/FT^3, and its specific heat is .24 B.T.U./LB. If we assume an outside air temperature of -30°F and an inside air temperature of 68°F. we get the following result:

5280 x .075 x .24 x 98 = 9314 B.T.U/HR.

Infiltration occurs through doors, windows, basement to main floor joints, breaks in vapour barrier, dryer vents, open doors, exhaust fans, and chimneys. A fireplace is particularly bad whether operating or not.

Present techniques of vapour barrier installation are much improved over pre 1975 methods, as are also door and window seals. Gas furnace chimneys are now being used which seal completely when the furnace is not operating. Some furnaces even cool the exhaust gases to the point where a dryer vent may be used as a chimney. This type of furnace has a much higher efficiency than the 70% to 80% of a regular type of gas furnace.

Infiltration reduction in older homes is inexpensive and gives a short payback period. It is the first step to be taken if one is trying to reduce heat loss. Infiltration reduction can be achieved through improvement to door seals, window seal, installing of storm doors and storm windows, dampers on all vents, except plumbing, fireplace doors.

A certain amount of air change must occur to prevent odor and humidity build-up, and to provide oxygen for the residents. Post 1975 houses typically have about 1/2 air change per hour. In a residence the air change usually can be reduced to about 1/4 air change per hour without problems. If this air change was accomplished by simply exhausting the stale air and replacing it with fresh outdoor air, the heat loss in the building covered by this report would be approximately 50% of the total heat loss from all other factors. The heat loss from air changes can be reduced by up to 90% if air to air heat exchangers are used. These air exchangers transfer the heat from the exhaust air to the inlet air by means of multiple adjacent passageways with heat conductive separaters.

6. BUILDING HEAT LOSS

Heat is lost from buildings primarily by conduction through walls, ceiling, floor, windows, and by infiltration. The heat loss by radiation is not significant due to the relatively low temperatures involved.

The heat loss by conduction through a wall is governed by the thermal resistance of the wall, but since the heat must flow from the inside air to the wall, and from the wall to the outside air, the resistance of these two junctions must be added to the thermal resistance of the wall to get the total resistance to heat flow. For example, the total thermal resistance of a wall using R20 fiberglas batts with 3/8" plywood exterior sheathing, x90 siding, 1/2" plasterboard would be 22.55 as shown below. (See table 6)

Inside Air to Wall	.68
Plasterboard	.45
Insulation	20
3/8" plywood	.47
Siding	.78
Wall to Outside Air	.17
	22.55

It will be noticed that, as the amount of insulation is increased, the other thermal resistances become almost insignificant in comparison, and are therefore sometimes neglected in calculating heat losses.

In the case of windows and concrete walls the surface resistances become a significant portion of the total resistance, and must therefore be considered.

In calculating the heat loss from buildings there are two approaches which may be used. The first employs an outside design temperature. In the case of a heating system which must be capable of supplying the entire heating load, the outside design temperature may be the record lowest temperature. For solar energy heating, or for buildings which need not be kept fully heated at all times, a higher design temperature may be used. Using an outdoor design temperature allows the calculation of the hourly heat loss which will occur at the design conditions, but gives no indication of a yearly heating requirement.

The second method of calculating heating load makes use of a factor called a degree-day. A one degree temeprature difference between indoor and outdoor temperature existing for one day is defined as one degree-day. In using this method one must determine the number of degree-days for the period of interest and also calculate the building heat loss for a temperature difference of one degree existing for one day. Weather office records indicate the number of degree-days per month for various locations. The figures are based on a particular indoor temperature which is usually 65^{o}F. Degree-days above a chosen temperature can be used in calculating cooling loads, and are available from weather records.

6. BUILDING HEAT LOSS CONT.

Table 8 shows the long term average degree-days per month for the Saskatoon Weather Station. It should be noted that degree-days cannot be accurately modified for indoor temperatures different from the one specified in the records, unless one has the raw data from which the degree-days were calculated. The following example will illustrate the use of degree-days:

Calculated Heat Loss Per Degree-Day	7000 B.T.U.
Annual Degree-Days for Saskatoon	10,938
Total Annual Heat Required 7000 x 10,938 =	76,566,000 B.T.U.

7. FEASABILITY OF SOLAR HEATING

In order to determine feasability a study will be done on a building measuring 20' x 30', having 8' walls and a concrete floor, on grade.

Firstly consider regular construction using pre-1975 insulation values, and a fuel burning heating system with chimney. Calculation of heat loss will be based on an outdoor temperature of $-30^{\circ}F$ and an indoor temperature of $65^{\circ}F$.

Walls (½" plasterboard, R12 insulation, 3/8" plywood, x90 siding)

R value is .68 + .45 + 12 + .47 + .78 + .17 giving 14.55

heat loss is $\frac{95(20x8x2+30x8x2)}{14.55}$ giving 5223 B.T.U./HR.

Ceiling: (½" plasterboard, R12 insulation)

R value is .68 + .45 + 12 giving 13.13

Heat Loss is $\frac{100(20x30)}{13.13}$ giving 4570 B.T.U./HR.

Note that a ceiling indoor temperature of $70^{\circ}F$ was used.

Floor: (4" concrete)

R value 10 (Table 6)

Soil temperature assumed to be $50^{\circ}F$.

Heat loss is $\frac{15(20x30)}{10}$ giving 900 B.T.U./HR.

Perimeter Heat Loss

Loss Factor .86 (Table 6)

Heat loss is .86 x 95 x (2(20+30)) giving 8170 B.T.U./HR.

Note that the temperature difference is

$95^{\circ}F$ since the perimeter is exposed to outside air.

Windows (six 2'x4' double glaze 1/2" air space)

R value 1.8

Heat Loss is $\frac{95(6x2x4)}{1.8}$ giving 2533 B.T.U./HR.

Correction To Wall Loss (for window area)

$\frac{95(6x2x4)}{14.55}$ giving -313 B.T.U./HR.

Total Conduction Loss	20,858 B.T.U./HR.
Plus Infiltration (25%)	5,215 B.T.U./HR.
Total Heat Loss	26,073 B.T.U./HR.

7. FEASABILITY OF SOLAR HEATING Cont.

Table 2 shows an average daily energy gain of 1090 B.T.U./HR./FT.^{2} for December and 1370 B.T.U./HR/FT^2 for January. Thus the number of square feet of collector required on sunny days, with a collector efficiency of 100% and an outdoor temperature of -30°F would be:

December $\frac{26,073 \times 24}{1090}$ giving 574 FT^2

January $\frac{26,073 \times 24}{1370}$ giving 456 FT^2

The above figures represent about twice the long wall area (30x8), and it would thus appear that this building could not be entirely heated by solar energy in relatively cold weather.

Considering degree-days in order to get a yearly evaluation gives the following results:

Total Heat Loss Per Day for a 1°F temperature difference is

$\frac{26,073 \times 24}{95}$ giving 6586 B.T.U.

This figure is an aporoximation since the floor heat loss is not air temperature dependent.

The total degree-days below 65°F for the months of Jan., Feb., Mar., ½ April, ½ Sept., Oct., Nov., Dec. from Table 8 is 10404, giving an annual heat load of 6586 x 10404 which is 68,528,744 B.T.U. The solar energy available for the months mentioned above is 191,140 B.T.U./FT^2 (Table 3, 72°, 100% efficiency)

Collector Area Required is

$\frac{68,528,744}{191,140}$ giving 358 FT^2 which is

again too large.

If a super-insulated building is constructed the following heat losses can be predicted:

Walls: (R44 insulation in place of R12)

R value is 46.55

Heat loss is $\frac{95(20x8x2 + 30x8x2)}{46.55}$ giving 1633 B.T.U./HR.

Ceiling: (R65 insulation in place of R12)

R value is 66.13

Heat Loss is $\frac{100(20x30)}{66.13}$ giving 907 B.T.U./HR.

7. FEASABILITY OF SOLAR HEATING CONT.

Floor: (4" concrete with R17.5 extruded polystyrene sub-floor insulation)

R value is 10+17.5 giving 27.5

Heat Loss is $\frac{15(20x30)}{27.5}$ giving 327 B.T.U./HR.

Perimeter (insulated with R10 extruded polystyrene)

Loss Factor .08 (Table 6)

Heat Loss is .08x95x(2(20+30)) giving 760 B.T.U./HR.

Windows: (six 2'x4' four glaze 1½" air space)

R value 9

Shutters R value 15

Total R value 24

Heat Loss $\frac{95(48)}{24}$ giving 190 B.T.U./HR.

Correction to Walls (for window area)

$\frac{95(48)}{46.55}$	giving	-98 B.T.U./HR.
	Total Conduction Loss	3719 B.T.U./HR.
	Infiltration (25%) (Super-sealed)	928 B.T.U./HR.
	Total Heat Loss	4647 B.T.U./HR.

The area of collector required with a collector efficiency of 100% and an outdoor temperature of -30°F will now be:

DECEMBER $\frac{4647x24}{1090}$ giving 102 FT^2

JANUARY $\frac{4647x24}{1370}$ giving 81 FT^2

Since the long wall area is 240 FT^2 it now may be possible to supply all of the heating requirement on sunny days, if there is storage for night-time heat requirements.

Using Degree-Days gives the following results;

Heat Loss Per Degree-Day is $\frac{4647x24}{95}$ giving 1174 B.T.U.

which again is an approximation.

Collector Area Required is $\frac{1174x10404}{191140}$ giving 64 FT^2

7. FEASABILITY OF SOLAR HEATING Cont.

One must keep in mind that the above figures are based on 100% efficiency of the energy collecting system. In practice it is difficult to achieve efficiencies much over 50%. The areas caclulated above would therefore have to be doubled, if the attempt was to supply all of the heating load by solar means.

8. COLLECTION OF SOLAR ENERGY

There are two main types of systems used for the collection and distribution of solar energy:

Active Systems

Active systems make use of other energy sources to move the collected solar energy from the point of collection to the region to be heated, or to a storage region. Generally electricity is used to accomplish the movement. Active systems usually have storage facilities to provide night-time heat and cloudy day heat requirements. The heat storage may consist of rock beds, or water tanks, or, more recently, phase change materials. Active systems are designed to supply a large percentage of the heating requirement and consequently are expensive. Their payback periods tend to be long and their maintenance costs relatively high.

Most of the early solar heating systems were of the active type. However during the last ten years there has been a definite move toward simpler systems.

Passive Systems

Passive systems do not make use of other energy sources to move the collected solar heat energy. Passive systems generally do not provide special heat storage facilities, and are usually designed to provide 50% or less of the heating requirement. They are consequently less costly than active systems, and tend to require less maintenance. Payback periods are relatively short. With a passive system a complete back-up heating system is required. Buildings using passive collecting systems are usually super-insulated.

Passive Collection Systems

Windows

The simplest passive system consists simply of south facing windows exposed to direct sunlight. Glass absorbs very little solar energy, so that most of the solar energy passes directly into the house and is absorbed by floors and furniture. Dark colored objects absorb more of the energy and are therefore preferable. A very small percentage of the energy will be reflected back out through the windows again, due to incomplete absorbtion in the room. In order to prevent summer overheating south facing windows should be shaded, so they are not exposed to the high summer sun. The shades should give complete noon shade for two months during the summer. Special low iron glass is made which has a lower solar energy absorbtion factor, however such glass is not as yet readily available in Saskatchewan.

Regular type windows have rather low R values (1.5 to 2.5) so that there is a considerable heat loss through them. For example on a $-30^{\circ}F$ day the loss will be $\frac{95(1)}{2}$ which is 47.5 B.T.U./HR. for each square foot of window (assume an R of 2). This amounts to 1140 B.T.U./day. In December the energy which could come through a vertical window is 1113 B.T.U./FT^2/DAY while in January it is

8. COLLECTION OF SOLAR ENERGY

1261 B.T.U./FT^2/DAY. Windows do therefore not give a net energy gain in very cold weather, however since some windows are desirable they should be palced as much as possible on the south facing walls.

Window performance may be improved using insulated shutters. The R values of the shutters should be at least R15 in order to obtain reasonable payback periods. The following example calculation will illustrate the value of shutters:

Heat Loss Without Shutters 1140 B.T.U./FT^2/DAY

Heat Loss With Shutters Closed For 16 hours is

$\frac{95(1)}{2} \times 8 + \frac{95(1)}{17} \times 16$ giving 469 B.T.U./FT^2/DAY

which results in a net daily gain of from 644 to 792 B.T.U./FT^2/DAY

during December and January, using an outdoor temperature of -30°F.

Shutters can be placed on either the inside or the outside of the window. Inside shutters have the following disadvantages:

1. They take up wall space when open.
2. When opened in the morning some condensation may form on the cool glass surface.

Outside shutters solve the wall space and condensation problems but are troublesome to operate unless power driven.

The R values of windows may be increased significantly by the use of larger air spaces between the panes. Still air has an R value of 6 to 7 as shown in Table 6, provided convection currents can be kept low. As the thickness of the air space increases the R value tends to rise because of the longer conductive path, but tends to reduce because of greater convection currents. The temperature difference across the air space also tends to affect the degree of convection current, and therefore the resistance. Analyzing the situation by theory alone is very difficult. However experimental work done by De Graaf and Van Der Hold, as well as by Mull and Reiher, has greatly simplified the matter. The results of their work has been put in graph form that shows the following relationship:

$\frac{\text{Actual Air Resistance}}{\text{Still Air Resistance}}$ Vs Grashof Number

8. COLLECTION OF SOLAR ENERGY Cont.

The Grashof number is a dimensionless number calculated by making use of air density, strength of gravitational field, width of sir space, viscosity of air, and the temperature difference across the air space. Making use of this information indicates that an air space of approximately 1" to 1½" is the best for double or triple glazed windows, under typical prarie winter conditions. These figures are supported by work done later by Robinson, Powlitch, and Dill.

If the best air space is 1" to 1½" why then are sealed window units built with air spaces of only 1/4" to 1/2"? The reason is explained by investigating the construction of these units. Commercially built sealed units are completely air sealed to prevent moisture entry into the air space. A special chemical is placed in the air space during manufacture, whose purpose is to absorb moisture or sealant vapours so that condensation will not occur when temperatures decrease. Because of the completely sealed air space a change in temperature will cause a change is air pressure within the air space with a resulting strain on the glass. If the width between the panes of glass is 1" to 1½" then the pressure fluctuation is sufficient to cause glass breakage. The reason for the glass breakage with large air spaces can be illustrated with the following example:

> Consider an air space of 1/2". Assume that each glass pane can flex 1/8" at its midpoint without breakage. Assume also that the flexing of both panes by an amount of 1/8" will add a slice of volume 1/8" thick to the air space (increase of 25%). According to the gas laws $\frac{PV}{T}$ is a constant for real gases.
>
> Assume an initial air temperature of $-30^{\circ}C$ (243 K). Assume a summer temperature of $30^{\circ}C$ ($303^{\circ}K$). Therefore if V is constant the new pressure would be $\frac{303}{243}$ times the intitial pressure, which is 1.24 times V. When the flexing of the glass occurs (1/8" each pane) the new volume will be 5/4 times the original which will reduce the pressure to very near its normal value, and prevent further flexing of the glass. With a 1½" air space the pressure ratio at constant volume is the same (1.24), but with 1/8" flex the volume ratio is only 13/12 which is 1.08 so that movement of the glass will continue and breakage will occur.

A solution to the problem is to use units which are sealed at the glass perimeter to prevent air infiltration into the building, but which are vented to allow for air expansion. The venting holes can be drilled into the wall cavity of the building, and thus be connected to an air region having approximately the same temperature as the window air space. In windows of this design condensation can occur after sudden temperature drops at the end of prolonged damp weather conditions. The vent holes however will allow a diffusion of the moisture into the wall cavity within a reasonable length of time. The size of the vent holes

8. COLLECTION OF SOLAR ENERGY Cont.

can be calclculated, however there are several parameters which are difficult to determine, and therefore various sized holes can be used to determine experimentally the optimum size.

Using 1½" vented airspaces the following R values can be calculated.

Number of Air Spaces	R Value
1	3.8
2	6.0
3	10.5

Regular commercial sealed units have R values of 1.5 to 2.8 using 1 or 2 air spaces.

9. COLLECTOR PANELS

A material with a high absorbtivity for solar energy may be placed in the path of solar rays to capture energy. The material so used will rise to a temperature above its surroundings and begin to radiate and conduct its heat to the surroundings. A cover plate of one or more layers of transparent material will reduce heat conducted from the sun side of the collector to the air. Each additional layer of glazing will reduce the conductive heat loss but it will also reduce the solar energy reaching the collector plate.

The heat collected in the panel may be removed by circulating a gas or a liquid on the rear side of the panel, or on both sides of the panel. The faster the circulation occurs the lower will be the temperature of the collector panel. Lower collector panel temperatures reduce the conduction heat losses through the cover plate, but also result in lower circulating coolant temperature. In the case of space heating the absolute minimum collector panel temperature would be the desired room temperature. However to achieve this would require infinite coolant flow rates, which would require infinite power for circulation. In practice a minimum collector panel temperature of at least 25^{o}F above the desired room temperature is desirable. If natural convective air flow is used to cool the collector panel it is difficult to keep the panel temperature low. Cooling fins on the collector panel or a ribbed panel will provide better heat transfer, and result in lower temperatures.

With collector panels it may be possible to have an insulated panel on the living space side, fitted with closable vents. Night time heat loss can then be reduced considerably. There will be no problem with condensation on the inner surface of the glass cover if the vents remain closed until the collector panel reaches a suitable temperature. Efficiency is also a function of collector panel temperature and therefore forced cooling of the panel increases efficiency. Forced cooling however also increases operating cost and increases capital cost.

An arrangement referred to as a "Trombe Wall" is sometimes used in solar energy collection. The Trombe Wall was developed in France in 1947. The device consists of a heat storing wall, usually of concrete construction, with one side painted a dark color and exposed to the sun's rays. The other side is exposed directly to the space to be heated. The dark side of the wall is glazed with one or two sheets of glass or other suitable material. Closable vents are located along the top and bottom edges of the wall. The dark side collects solar energy and if the vents are open this heat energy flows into the space to be heated. If heat is not required the vents are closed and the heat is absorbed into the thermal mass of the wall. At night the vents can then be opened allowing air flow up both sides of the wall to transfer the stored heat to the living space.

10. PAYBACK PERIODS

Payback periods depend on several parameters: the present cost of construction of the energy conserving feature, interest rates, now and future, the present cost of energy, and the energy inflation rate. The interest rate and the energy inflation rate tend to cancel in their effect and in fact do if they are at the same level. Table 10 to 12 are based on zero interest rate and zero inflation rates. Allowance for additional labor cost has been allowed where noted in the Tables. No labor allowance indicates that there is neglegible extra labor to add the extra insulation. Table 12 indicates payback periods for the features used in the building covered by this report. No allowance was made for labor, however an amount equal to the material could be added which would result in a doubling of the payback times. The following items are worthy of note:

Table 10

1. Allowance for cost of larger studs and plates has been made where necessary.

2. There is a law of diminishing returns in the addition of insulation.

3. Extruded polystyrene is ralatively expensive and its use in walls is questionable from a financial point of view.

Table 11

1. Ceiling insulation has a short payback because of no additional structural cost, and higher ceiling temperatures.

2. No labor has beer allowed in Table 11 since adding extra insulation could be done by the home owner. If done by a contractor one could double the material cost to allow for labor.

Table 12

1. The calculations are done on the basis of commercial electrical rates since the building has a separate meter, which puts it in a commercial class. The energy cost is thus about twice the rate for electrical energy at residential rates.

Table 13 shows a comparison of energy costs for various types of fuel. If one were using fuel oil as an energy source instead of natural gas then a payback period of 18 years from Table 10 or 11 would change to 18 x 1/2.76 giving 6.52 years.

Graph 14 shows the correction factor to be used on payback periods when interest and inflation are considered. They are based on the assumption that the capital cost could have been invested instead of being spent on the energy saving feature. Therefore the interest rate used in this graph is the investment instest rate. It is also assumed that the yearly money saved is also invested at the same rate, with the yearly amount saved inflating at the energy

10. PAYBACK PERIODS cont.

inflation rate. It is important to note that the inflation rate used is the energy inflation rate, not the cost of living or general inflation rate. The graph is used in the following way: suppose a certain project has a payback period of 10 years with no consideration of interest or inflation. Suppose that the present interest is 20% and the expected energy inflation rate is 30%. From the graph the correction factor for F=30, R=20 and T=10 is approximately .71. The actual payback period will be 10 x .71 giving 7.1 years. Note that for a 25 year period using the same inflation and interest rates the correction factor is approximately .54 giving a 13.5 year payback. Note also that in the last example the predicted interest and inflation rates must hold true for only 13.5 years, not 25 years, for the calculation to be correct.

11. GARAGE SPECIFICATIONS

Location: 34 Antrim Street, Lanigan. Lat. 51° 50' N. Long. 105° 02'W.
Orientation: Magnetic directions. Variation at Lanigan 17°E
Interior Dimensions: 18'x30'x8'
Floor: 3½" concrete 3000 PSI reinforced with #3 rebar. 3½" extruded polystyrene layed below concrete in 3 layers. (1", 1½", 1")R value 17.5 perimeter of floor formed at 45° and insulated with 2"x24" R 10 extruded polystyrene layed at 45° with top edge flush with top of floor.

Walls: Double 2 by 4 studs 24" O.C. spaced 5" apart giving a wall thickness of 12" plus 1/2" plasterboard plus 3/8" spruce plywood plus x-90 siding. Insulated with two layers R 12 fiberglas running vertically and one layer of R 20 running horizontally. Single plates at bottom, single plates at top plus 1/4" plywood to join the two walls. The studs are not staggered. The outer wall is bolted to the concrete floor. 1x2 tie straps spaced 4" O.C. hold the bottom plates at the correct spacing.

Ceiling: 1/2" plasterboard on truss rafters 24" O.C. insulation R 20 fiberglas batts plus R 45 cellulose fiber.

Vapor Barrier: 6 Mil Polyethelene with all joints caulked. All window and door openings caulked and sealed with plastic angle moulding.

Wiring: On the surface in metallic conduit.

Ventilation: Exhaust - 34" propeller type 6 bladed fan 1000-6000 C.F.M. with two R 15 sealed doors.
Inlet - 32" square with two R 15 sealed doors.

Back Up Heat: 4000 W 220 V electric furnace.

Windows: South-four 32"x36" triple glaze R 6 effective area 28.3 $FT.^2$ R 15 outside shutters.
North - two 32"x36" four glaze R 10.5 effective area 14.2 FT^2 R 15 outside shutters.
East - One 36"x48" triple glaze R 6 effective area 10.86FT^2 R 15 outside shutter

Collector Panels, Forced Cooled
South - located in south side of attic at 19° from the vertical six 32"x48" double glaze with 3" ribbed collector. Collector panels - galvanized metal painted with flat black lacquer. Effective capture area 57.5 FT^2
East - in east wall, vertical. One 36"x48" double glaze. Same collector panels as attic collectors. Effective capture area 10.86 FT^2.
South - vertical, four 32"x48" double glaze, same construction as forced cooled type. Effective capture area 38.32 FT^2

Doors: Walk-in 32"x81" double doors, each door R 15 fitted with special seals.
Vehicle - 85"x111 single door, in two parts, R 44 fitted with Two sets of special seals.

12. BUILDING CONSTRUCTION NOTES

(a) Floor

The soil consisted of a sandy loam, over which a mixture of clay, sand, and gravel had been placed several years previous to construction. The area had been somewhat compacted due to vehicle traffic. Four inches of gravel fill was placed over the area, and wet compacted, followed by two inches of loose gravel fill. There was some concern over the support provided by the extruded polystyrene for the concrete floor. It was reasoned that if the lower layer of polystyrene was supported on only a small number of pebbles, then the floor loading might cause compression of the pebbles into the polystyrene with consequent floor failure. To help prevent this problem each sheet of polystyrene was aggitated by hand in order to get a well distributed support. In some cases additional gravel had to be placed under the sheets to obtain proper support.

Using three separate layers of polystyrene gave a superior R value since there were no complete vertical gaps in the insulation. The use of three layers as opposed to one thick layer did suggest possible weak support areas as shown below in exaggerated form.

The floor was reinforced with #3 rebar to prevent vertical movement if cracks did occur. The floor was poured in June of 1980. The building was not kept heated continuously during the winter of 1980-81 and consequently the floor and probably the soil under the floor did freeze. Several small cracks did occur in the concrete, but to date (February, 1983) the cracks have not miss-aligned vertically and have thus not caused any problem. The cracks occured previously to any vehicle being driven over the floor. It has not been determined whether the cracks were caused by poor floor support, soil movement from frost, or some other cause.

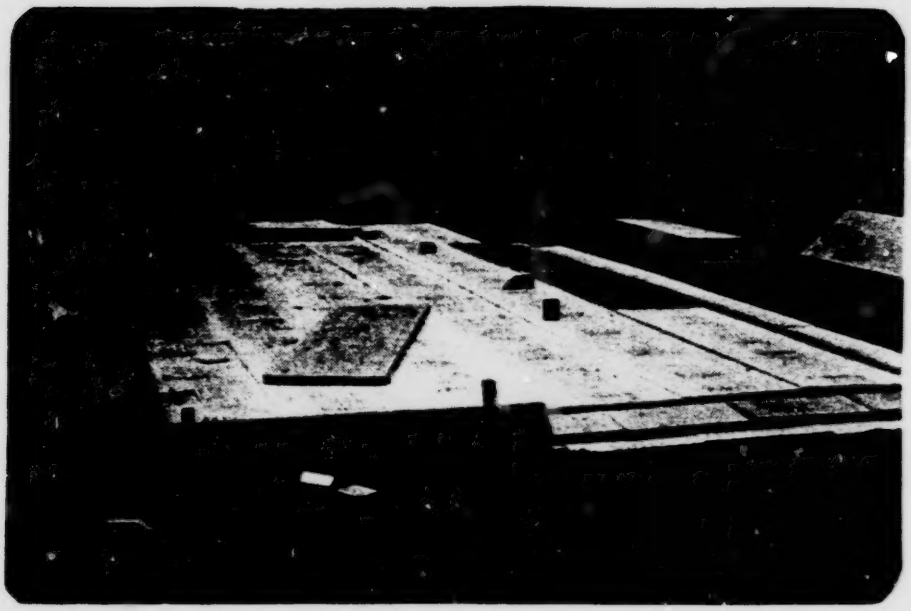


Photo #1 - Extruded polystyrene being layed.

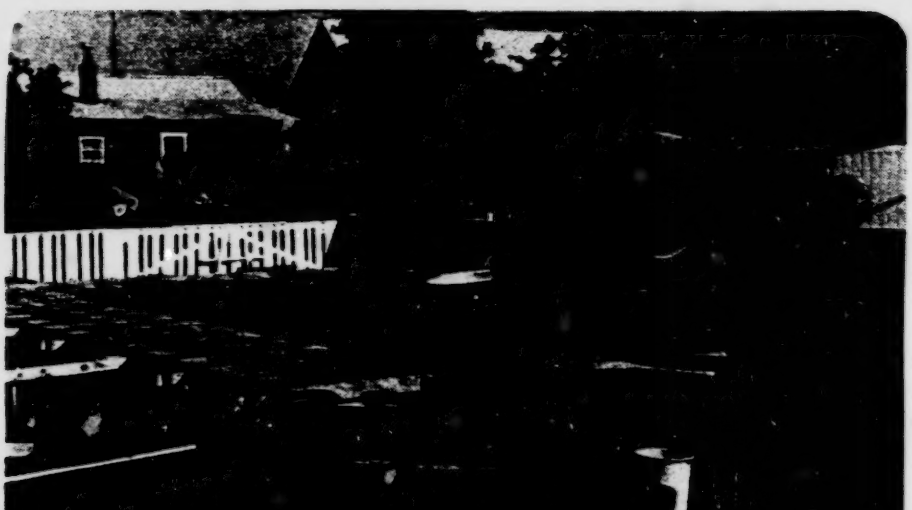


Photo #2 - Area ready for concrete placement

12. BUILDING CONSTRUCTION NOTES

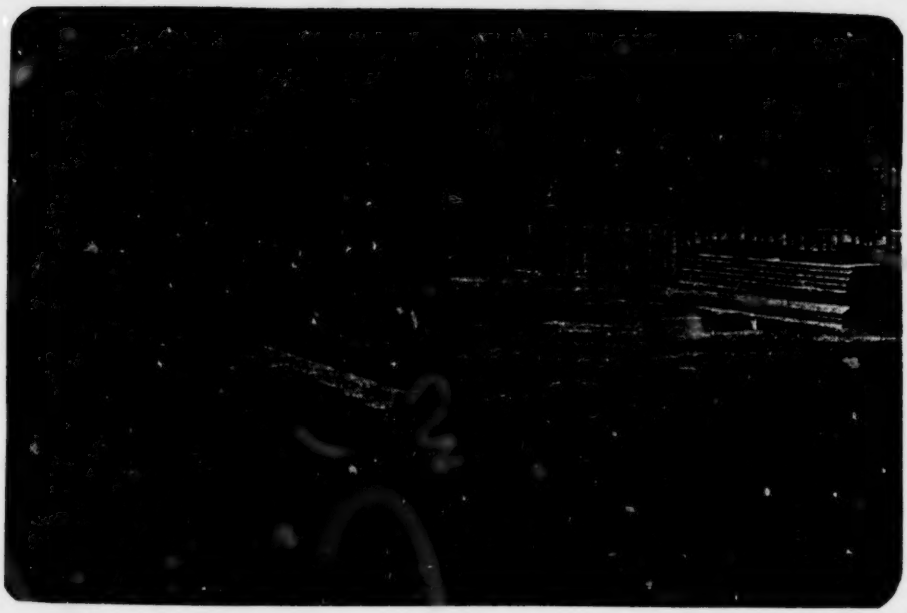


Photo #3 - perimeter insulation

(b) Walls

The double 2 by 4 wall construction was chosen for two reasons:

1. To prevent a direct wood conduction path through the wall.

2. To allow the use of low quality, inexpensive studing.

Objective one was accomplished by spacing the two walls 5" apart, and using only 1/4" plywood to join the top plates and only 1x2 straps spaced 4'O.C. to join the lower plates. The window frames do give a direct wood heat loss path, but they are constructed of 1/2" plywood to reduce the area of the heat loss path.

Objective two was accomplished by building the inner and the outer wall with matched stud spacing. This allowed the use of curved studs since with proper placement they could be held straight with small tie strips or spacers. If the building were contracted out then it is doubtful if the material savings of using economy studs would overcome the additional labour cost involved.

Studs were spaced 24"O.C. to reduce wood heat loss paths. Each outer wall was built first, on the concrete floor, then the inner wall was built on top of the outer wall. Using this method assured good stud matching as well as window frame alignment. The outer walls, less the sheathing, were erected first and bolted into place. The inner walls were then erected and tied to the outer walls with 1/4" plywood at the top and 1 by 2 straps at the bottom. The walls were squared and the 3/8 spruce sheathing applied. Acoustical sealent was used to reduce air flow through the walls in windy conditions.

12. BUILDING CONSTRUCTION NOTES

(b) Walls cont.

The sealent was applied at all plywood joints and along the bottom and top edges of the plywood. Accoustical sealent remains flexible in sub-zero temperatures. Theoretically any moisture in the wall cavity should be able to pass out through the plywood sheathing at a sufficient rate to keep the humidity at a reasonable level. As mentioned later in the operating notes on windows, there was some problem encountered with wall moisture. It is therefore recommended that the exterior sheathing not be sealed.

There is a slight value in staggering the studs to reduce heat loss through the wall. The following example will illustrate the advantage.

Consider 24" stud spacing not staggered, and consider the 24" region to be subdivided into 18 regions each of 1½" width. The region containing the studs will have a thermal resistance of 2(3.5)(1.4) plus 5(3.7) (See Table 6) giving 28.3. The other regions will each have a thermal resistance of 12(3.7) giving 44.4. Thus the total conductivity of the wall will be proportional to 1/28.3 plus 17/44.4 giving .41822. If the studs are staggered then there will be two regions having a thermal resistance of 3.5(1.4) plus 8.5(3.7) and 16 regions having a thermal resistance of 44.4. The total conductivity of the wall will be proportional to 2/36.35 plus 16/44.4 giving .41538 . The percentage reduction in thermal conductivity is thus (.41822 - .41538)(100)/.41822 giving .679% . The reduction in heat loss is therefore not significant.

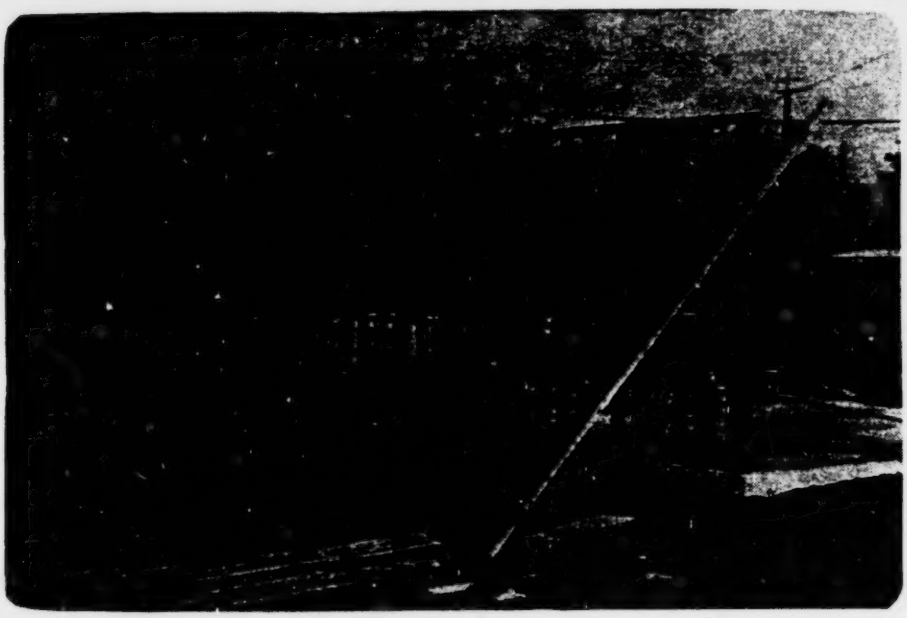


Photo #4 - Erection of walls

Photo #5 - Sealing of sheathing and lower plate.

(c) Rafters

Rafters were designed to be spaced 24" O.C. to match the wall stud spacing and also to reduce the number of wood heat loss paths. The rafters were designed so that there was space over the top of the walls to provide a high insulation level. In order to achieve this it was necessary to use an 18" eve overhang. The rafters also provide the support for the upper collector shade as well as support for the lower collector shade. The rafters also provided members to which the upper collector ductwork was later attached. Construction was of spruce 2x4 with 5/16 plywood gussets nailed with 1½" coated nails.

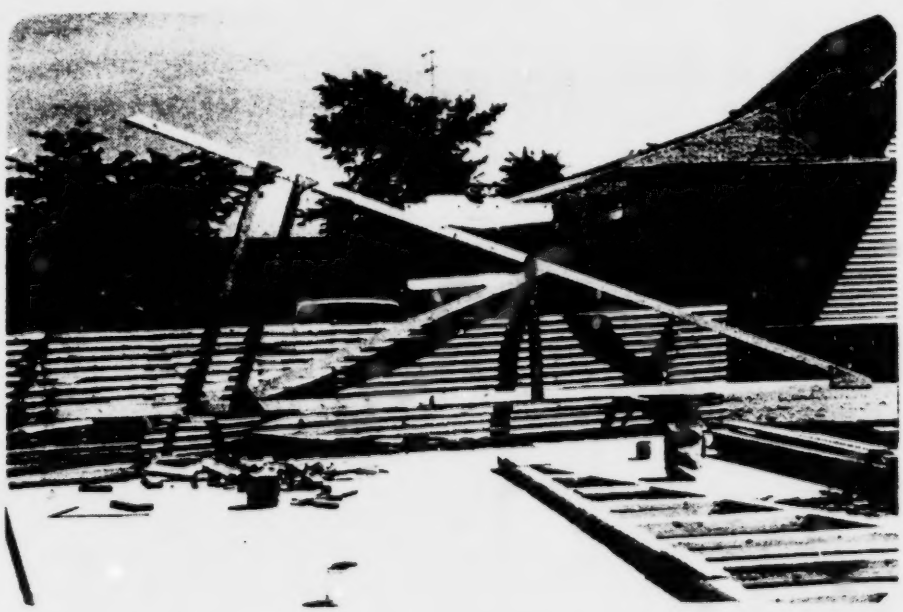


Photo #6 - Rafter details

12. BUILDING CONSTRUCTION NOTES Cont.

(d) Windows

The window frames were constructed of 1/2" fir plywood. The corners had lap joints fastened with coated nails. All four sides were attached to the rough frame opening using coated nails and double tapered shims. A total clearance of 1/4" in width and 1/4" in height was allowed for the glass, which proved adequate. Double diamond glass was used for all windows and collectors. The spacer channels were formed from 28 ga. galvanized iron sheeting, having a width of 1½" and a height of 3/4", with the ends cut at 45 degrees after forming.

One problem was encountered in the forming of the channels. The only shear available had a length limit of 36", however, some of the channels were to be 48" in length. The blanks for the 48" channels were cut using a rotary wheel cutting machine. The blanks were then bent using a regular metal brake. After bending the channels were curved due to metal stretch caused by the pressure of the cutting wheels. The channels so curved were discarded and new blanks cut with hand shears.

The assembly of the window units was accomplished in the following manner. The metal channels were attached to the 1/2" plywood frame using three wood screws in each. No attempt was made to seal the channels. The glass was then placed against the metal channel, and held by hand while accoustical sealant was applied to the perimeter of the glass in the corner formed by the glass and the plywood window frame. The bead of sealant was from 1/4" to 3/8" in height. Pre-painted 3/4" square wood strips were then pressed against the glass and sealant and attached to the plywood frame using three wood screws.

A glass breakage problem occured with some of the window units. The breakage occured when the glass temperature rose in the solar collectors. It was determined that the breakage was caused by a high side pressure on the glass. The pressure was caused by thermal expansion of the metal channel. The wood strips had been pressed too tightly against the glass during installation, leaving too little space for expansion. The pressure applied to the wood strip had been sufficient to squeeze much of the sealant completely out of the contact region between the glass and the wood strip. There was thus very little sealant remaining to absorb movement. When the broken glass was replaced much less pressure was used on the wood strip, which resulted in no further breakage.

12. BUILDING CONSTRUCTION NOTES Cont.

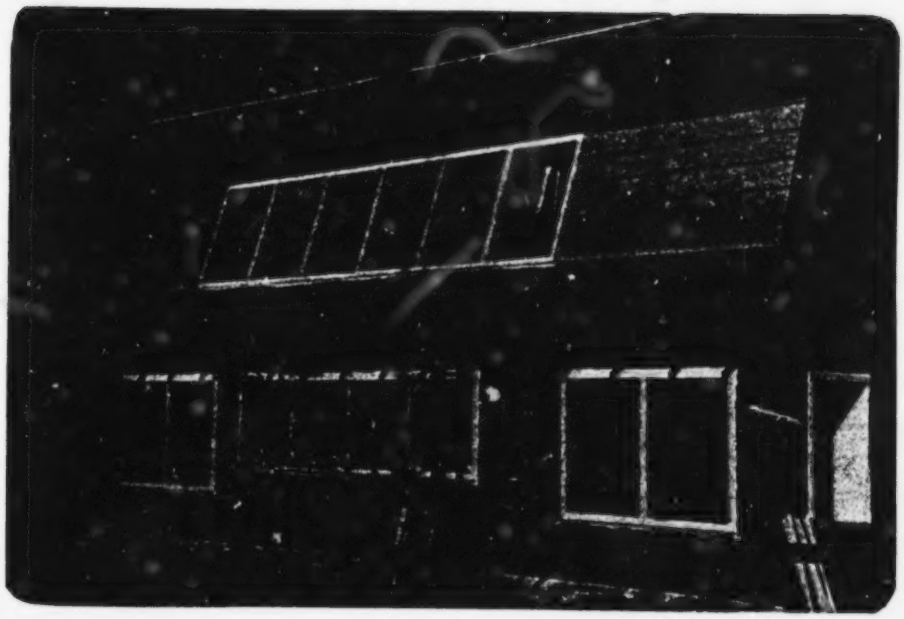


Photo #7 - window frames

Photo #8 - window channel in place

12. BUILDING CONSTRUCTION NOTES Cont.

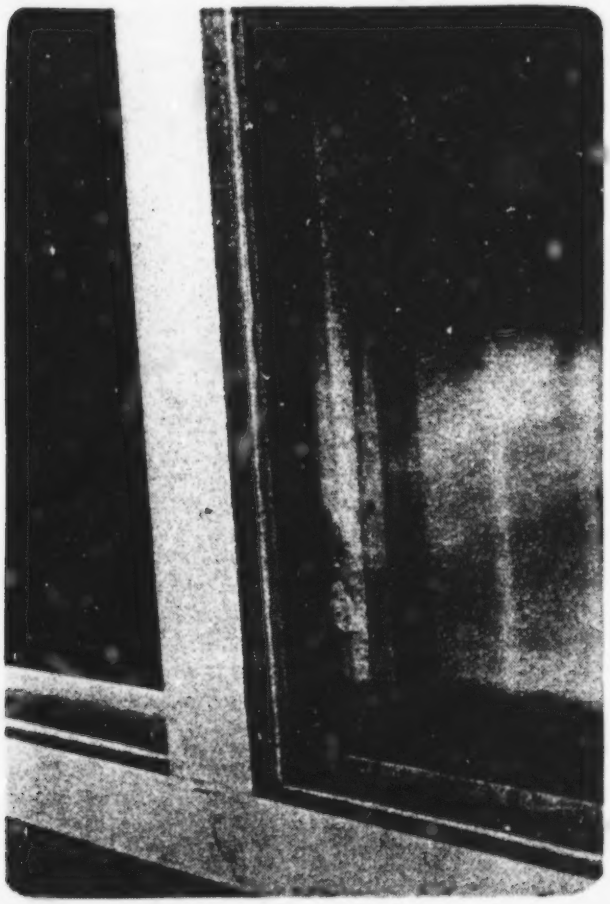


Photo #9 - glass and sealant in place

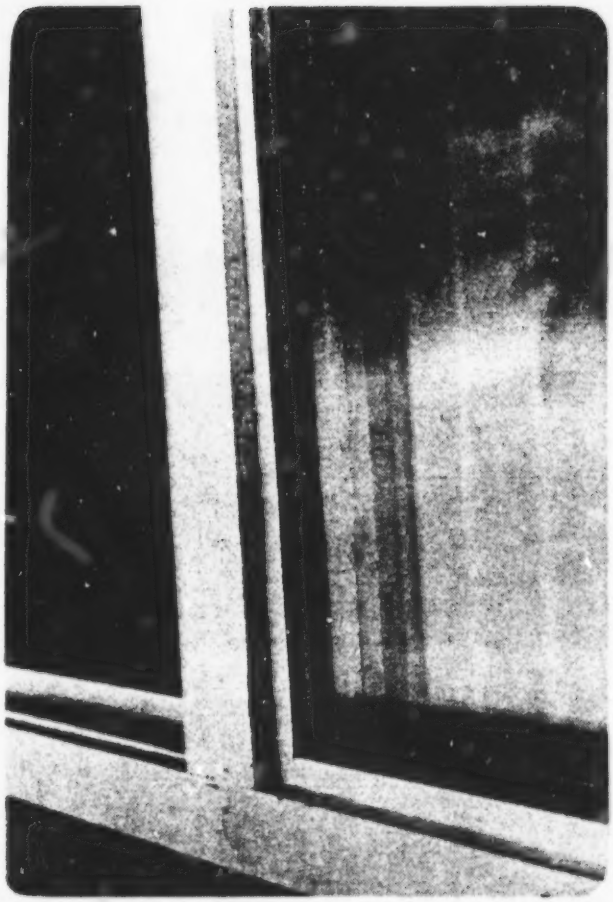


Photo #10 - wood strip installed

(e) Insulation

Walls - The vertical R 12 batts were installed in the outer wall space, followed by the horizontal R 20 batts in the space between walls, followed by the vertical R 12 batts in the inner wall space. Particular attention was given to proper fit in corners and around windows and doors. No special problems were encountered during the installation of the wall insulation.

12. BUILDING CONSTRUCTION NOTES Cont.

Solar Collector Ductwork - The upper solar collector ductwork was insulated with R 20 fiberglas batts held in place with small horizontal wood strips. No vapour barrier was used on the ductwork. The inner removable wall of the lower solar collectors was also insulated with R 20 fiberglas batts. In this case 6 mil vapour barrier was used between the insulation and the inner plywood sheathing.

Celing - After installation of the vapour barrier and plasterboard the R 20 fiberglas batts were installed from the upper side. The celulose fiber was then blown in over the fiberglas. There were no problems encountered during this operation. There was concern over the amount of settling which would occur if all the insulation (R 65) had been cellulose fiber, since cellulose fiber appears to have a lower compressive strength than fiberglas batts. The cellulose fiber however does give a better fit around rafter braces than does the fiberglas batts.

Photo #11 - wall insulation

Photo #12 - Ductwork insulation

12. BUILDING CONSTRUCTION NOTES Cont.
(f) Vapour Barrier

The vapour barrier used was 6 mil polyethylene in a 20 ft. width. The ceiling barrier was installed first with the aid of a rope tied across the studing from wall to wall, to help support the plastic. The barrier was attached to the rafters with a power stapler. The use of a 20 ft. wide roll allowed a 1 ft. drop along each wall since the inside building dimension was 18 ft.

The wall vapour barrier was then installed and sealed to the ceiling barrier with a bead of acoustical sealant placed in line with the upper wall plate. The bottom of the wall barrier was sealed to the floor with a bead of sealant along the corner formed by the lower wall plate and the floor. The barrier was left intact across all window and door openings until the plasterboard had been installed. The plastic was then cut leaving approximately 2" of material for sealing purposes. A bead of acoustical sealant was laid along the edge of the 1/2" plywood window frames and door frames, and the barrier pressed into this bead. Outside plastic corner moulding measuring ½"x½" was then pressed over the corner and nailed to the window and door frames with small brass tacks. The surplus barrier was then cut and removed and the window casing nailed in place to further hold the plastic moulding.

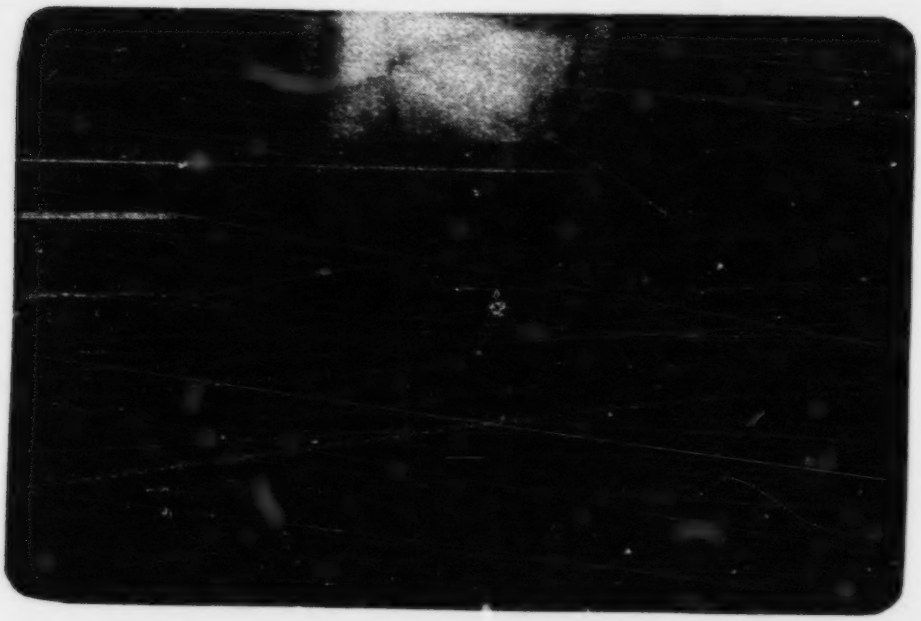


Photo #13 - sealant in place

12. BUILDING CONSTRUCTION NOTES Cont.

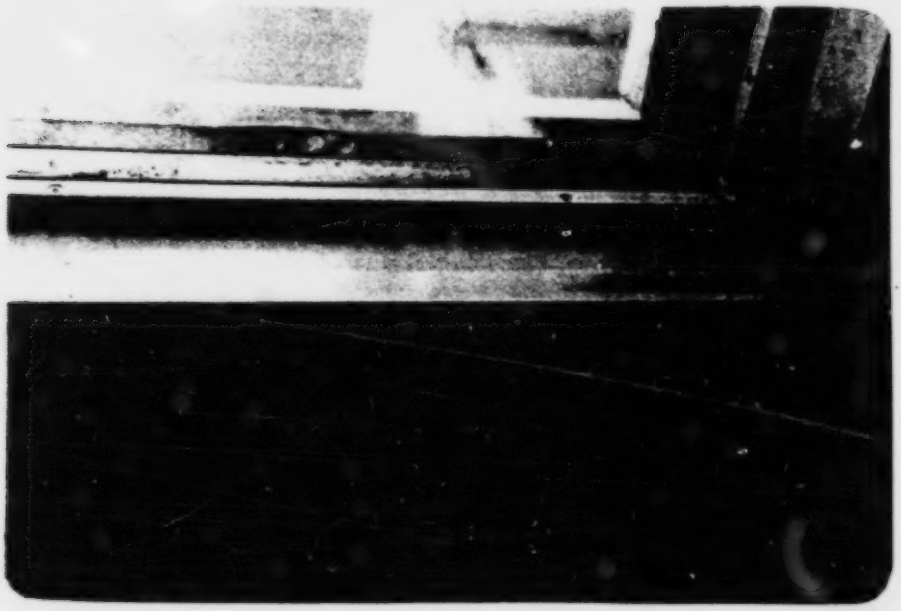


Photo #14 - Plastic moulding installed

Photo #15 - Window casing installed

(g) Doors

The walk-in doors were constructed of 2x4 frame ripped to an actual width of 3 1/4", covered each side with 1/4" fir plywood. Insulation consisted of two layers of 1 1/2" extruded polyetyrene giving an R value of R 15. The inner door had 6 mil vapour barrier under the inside plywood. The seals were constructed of 1" thick plastic foam covered with high quality, low temperature, two-way stretch cloth-backed vinyl. Heat was used to mould the vinyl at the

12. BUILDING CONSTRUCTION NOTES Cont.

(g) Doors cont.
corners of the door. The vinyl was fastened to the door with a power stapler. All edges of the door were tapered to fit into the tapered door frame. The door frame was constructed of 1/4" hardboard held in place with wood screws. The corners of the door frame were formed of plywood covered with aluminum. The corners and all wood screw heads were filled with auto body fill. Automatic door vents were required to allow the opening and closing of a door when the other door had been previously closed.

The main vehicle doors were constructed in the same manner as the walls, using double 2x4 studs with a 5" spacing. Both sides of the doors were sheathed with 1/4" fir plywood. A 6 mil vapour barrier was used under the inside plywood. The doore were tapered on all edges except the hinge edge. Double seals were used, which had the same construction details as used on the walk-in doors. Insulation was fiberglas batts giving an R value of 44. The doors were made of unequal size so that the opening of the larger door only would be sufficient for the entry of a snowmobile. The unequal door size also resulted in one door having no joint in the plywood sheathing.

The wall opening for the doors was tapered on the top and bottom only, with the hinge sides being straight. The lower part of the wall opening was formed by attaching 5/8" pressure treated plywood to the sloped concrete using lead plugs and screws, and then attaching 1/4" hardboard to the plywood using wood screws. Acoustical sealant was used at all interfaces. The top surface of the hardboard was primed and painted. All corners were formed in the same manner as used in the walk-in doors. At the door joint the seals of the large door fit against the tapered edge and curved extension corners of the smaller door.

12. BUILDING CONSTRUCTION NOTES Cont.

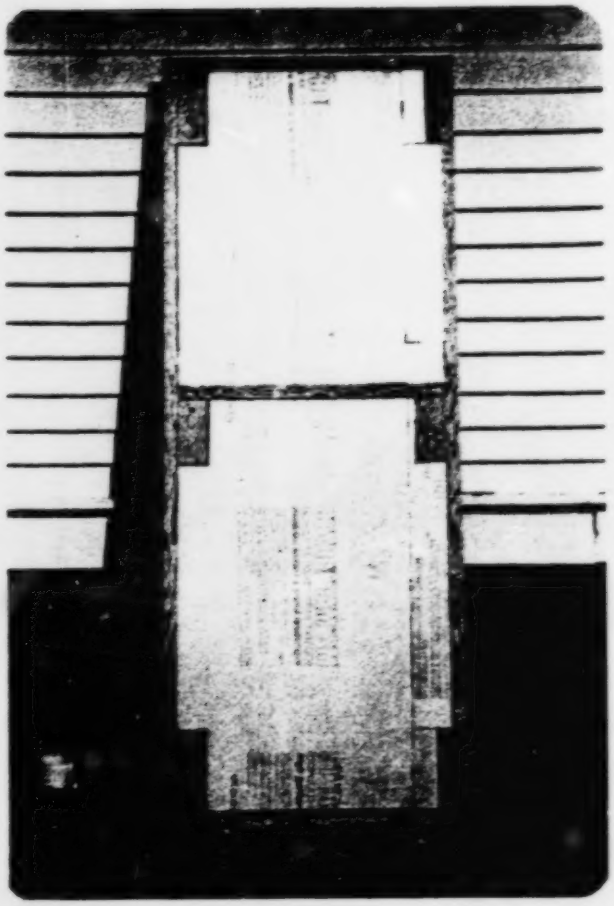


Photo #16 - Walk-in door construction

Photo #17 - door seal construction

Photo #18 - walk-in door vent and closure

12. BUILDING CONSTRUCTION NOTES Cont.

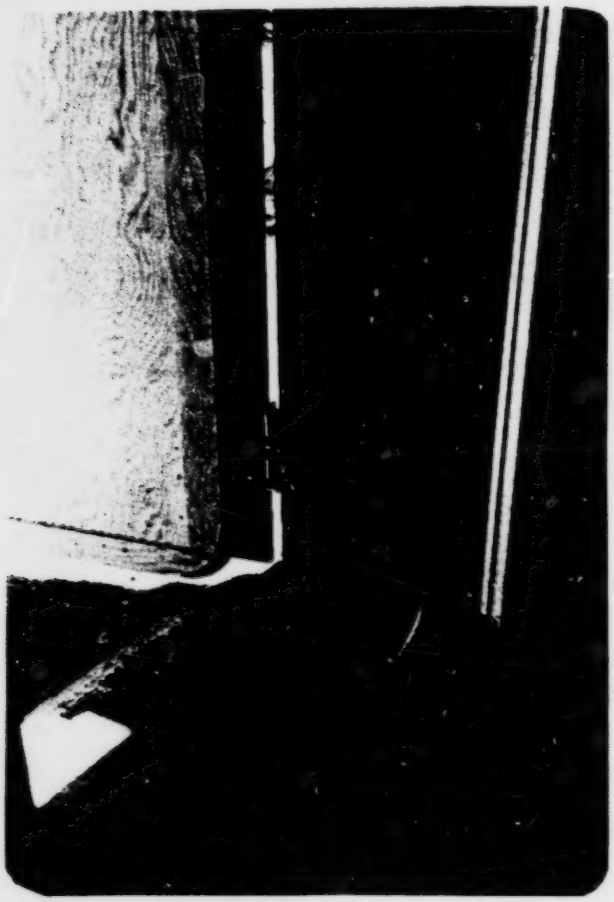


Photo #19 - walk-in doors installed

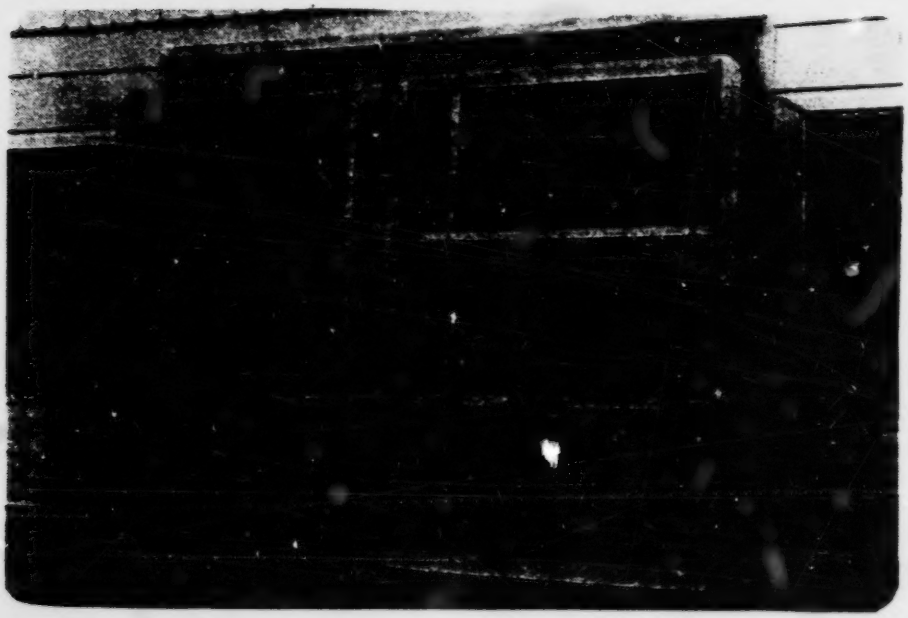


Photo #20 Vehicle door construction

13. BUILDING CONSTRUCTION NOTES Cont.

Photo #21 - Finished vehicle doors.

(h) Ventilation

The exhaust fan runs at 240 R.P.M. driven by a 1140 R.P.M. 1/3 H.P. 110V.A.C. motor by means of a standard V-belt drive. The fan is designed so that it fits entirely between the two insulated doors. The fan is constructed on a 3/4" shaft, using self-aligning pillow block bearings. The arms are of 3/16"x1" flat iron welded to the shaft at equal intervals. Blades are constructed from 26 ga. galvanized iron, bolted to the arms.

The doors are 3" thick and contain R 15 extruded polystyrene insulation. They are built on a 3/4" lumber frameand use 1/4" fir plywood for sheathing. The inside door contains a 6 mil vapour barrier. The doors are linked together so that opening the inside door also opens the outside door. They are balanced to stay in any position selected.

12. BUILDING CONSTRUCTION NOTES Cont.

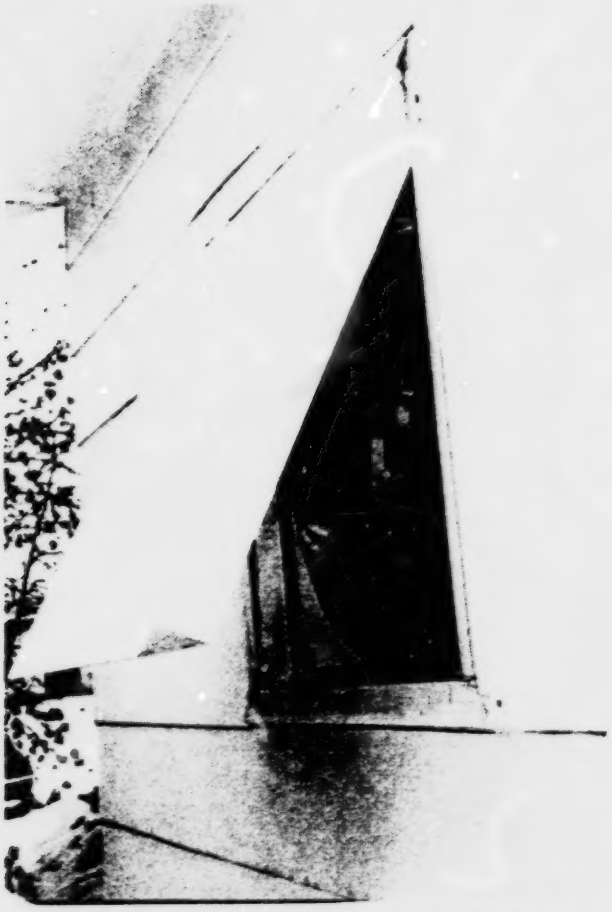


Photo #22 - Exhaust fan, outside view

Photo #23 - Exhaust fan, inside view

12. BUILDING CONSTRUCTION NOTES

Photo #24 - Air inlet

(i) Solar Collectors

The upper collectors were double glazed with construction similar to the building windows. The collector panel was spaced 3/4" from the inner glazing. Hardboard was placed 3/4" from the inner side of the collector panels. The hardboard was 4" shorter than the collectors in order to allow air movement into and out of the collector. The balance of the ductwork was constructed as shown in Figure 1 and Figure 2.

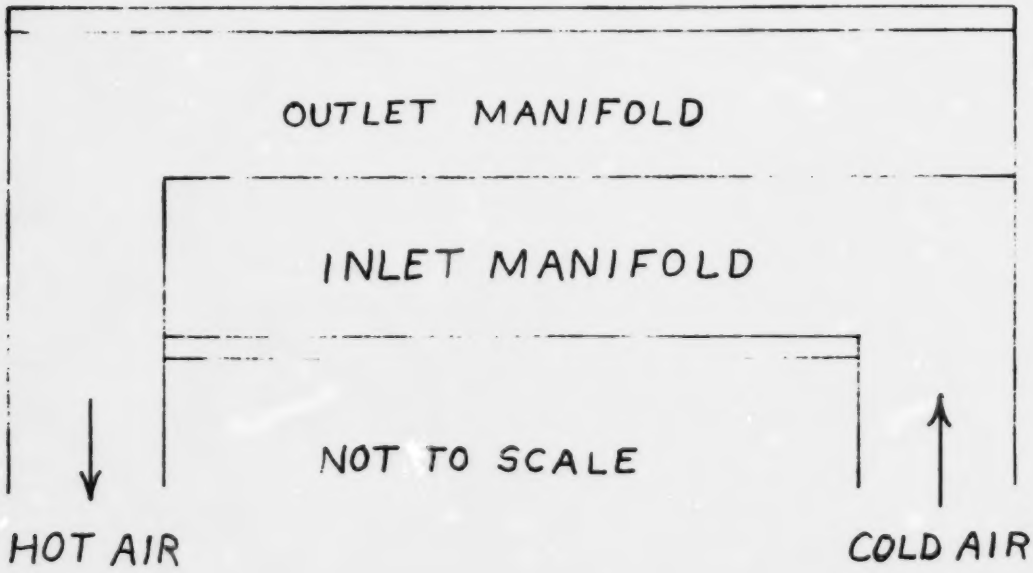


Figure 1 - Upper collector - side view

12. BUILDING CONSTRUCTION NOTES Cont.

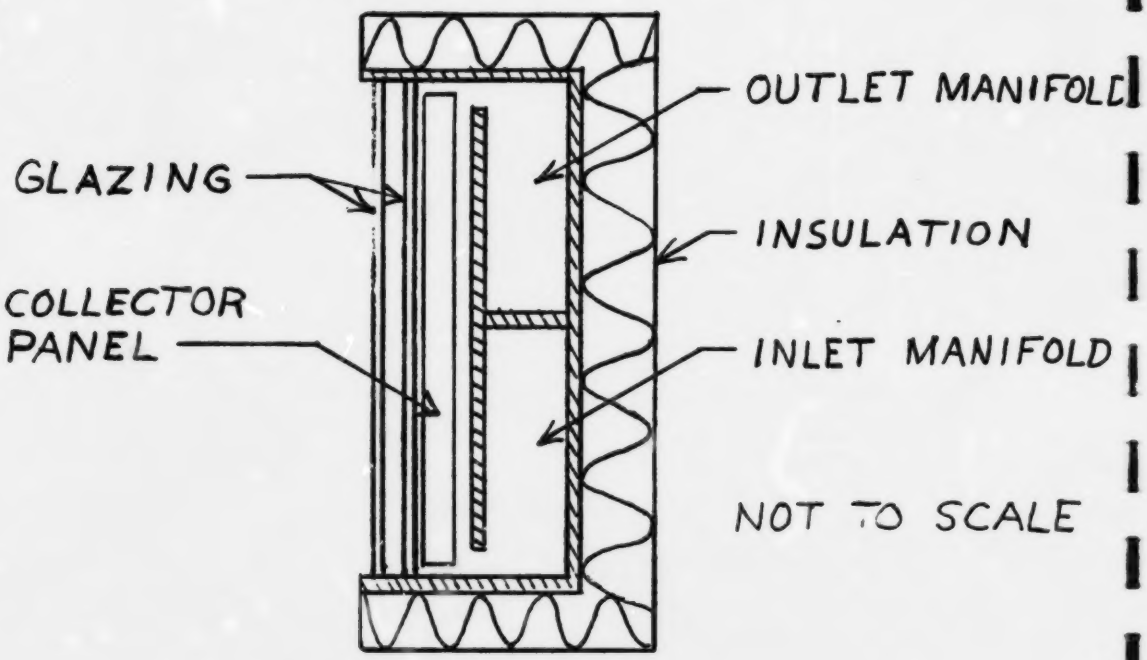


Figure 2 - Upper collector - end view

The collector panels were slightly shorter than the air duct work to allow approximately 5% of the total air flow to pass through the space between the collector panel and the inner glazing. The balance of the air was forced up between the 1/4" hardboard and the collector panel. All joints were sealed with acoustical sealant and most connections were made with wood screws. The air was blown through the collector with an 8" centrifugal blower powered with a 1/8H.P. 110V.A.C. motor. Pressure sensistive dampers were used at both the inlet to the collector and the outlet from the collector to the building. Control of the blower is by means of two thermostats. The upper thermostat is located in the collector ductwork and closes at approximately 80°F. and the lower one is in the building and is adjustable in the normal manner. The thermostats are in series with the power lead to the motor so that both thermostats must be closed for motor operation.

The south wall collectors were also double glazed with construction similar to the building windows. The collectors were installed in the one foot thick walls, with the glazing located near the outer edge of the opening. The collector panel was spaced 3/4" from the inner glazing. The panels were shorter than the collector opening to allow approximately 10% of the air flow to take place between the collector and the inner glazing. The building side of the ductwork consisted of a 6" thick insulated section of wall with an inner sheathing of 1/4" fir plywood large enough to attach to the casing of the collector opening. A 6 mil vapour barrier was used under the inner sheathing. The wall section was shorter than the collector wall opening to allow air flow in at the bottom and out at the top. Originally it was intended to use natural air flow on some of the wall collectors. These natural flow units would have thermostatically controlled dampers at the top and bottom to control air flow. Tests done during the winter

(i) Solar Collectors

of 1982 determined that the efficiency of the natural flow units was less than one half of that of a forced cooled wall collector. These findings are presented in the conclusion section of this report. After the efficiency tests the natural flow collectors were converted to forced flow type. Two units are connected together and have a common air inlet blower and a common air outlet. Both the inlet air duct and the outlet air duct have pressure controlled dampers. Electrical control was of the same design as used in the upper collectors. Construction details of the wall collectors are shown in Figure 3.

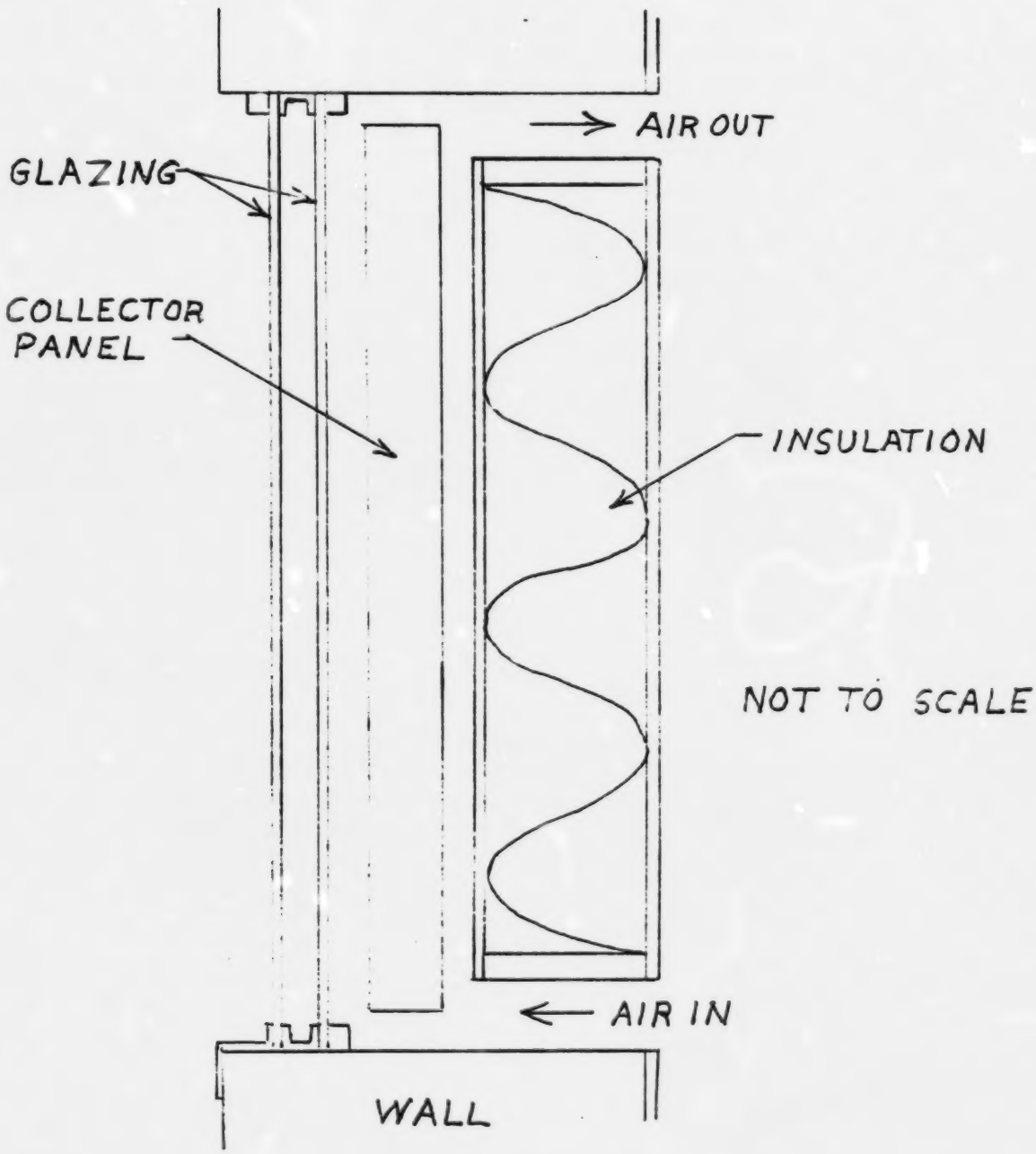


Figure 3 - Wall collectors - side view

12. BUILDING CONSTRUCTION NOTES Cont.

(i) Solar Collectors

The collector panels for all solar collectors were formed from 28 ga. galvanized iron. The sheets were cut to dimensions of 46½" by 96" and then run through a bending machine which formed S bends of 3" width. The bent sheets were then run through a squeezing machine to reduce the overall size to 46½" by 36", or 46½" by 48" depending on collector opening dimensions. The S bends were used to increase the ratio of the surface area to the solar capture area, in order to get better heat transfer to the cooling air. The collector panels were painted after the bending process was complete. The painting procedure consisted of preparation with "metal prep", priming with zinc chromate, sealing with a special primer-sealer, and finally painting with a flat black lacquer. All coatings were applied by spray except the metal prep which was a wipe on, flush off, type of material. Lacquer does not normally stand weathering as well as enamel, however in the collector application the surface is exposed only to solar rays, not moisture. Lacquer does have a slightly better solar obsorbtion factor than enamel.

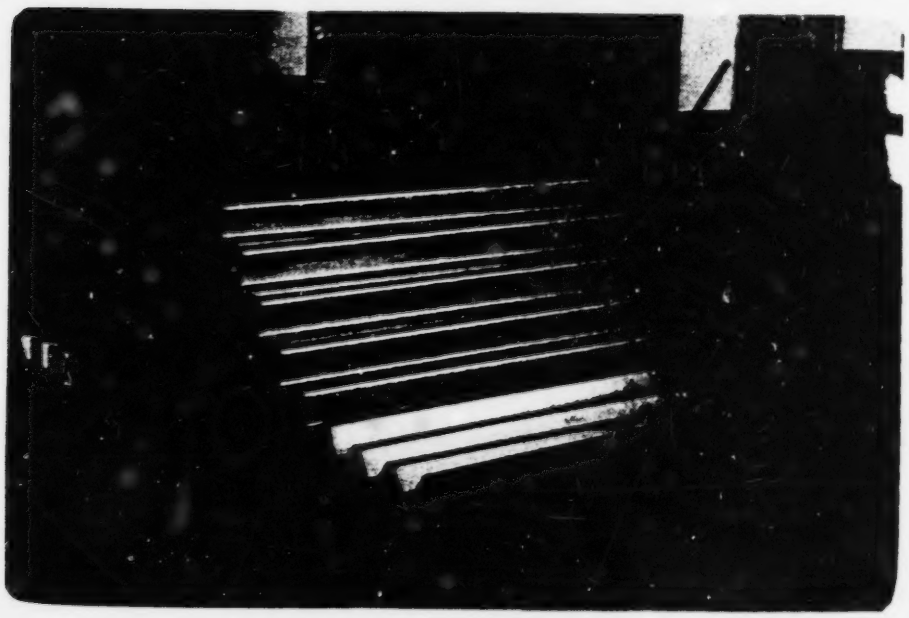


Photo #25 - bending of panels

12. BUILDING CONSTRUCTION NOTES Cont.
(i) Solar Collectors cont.

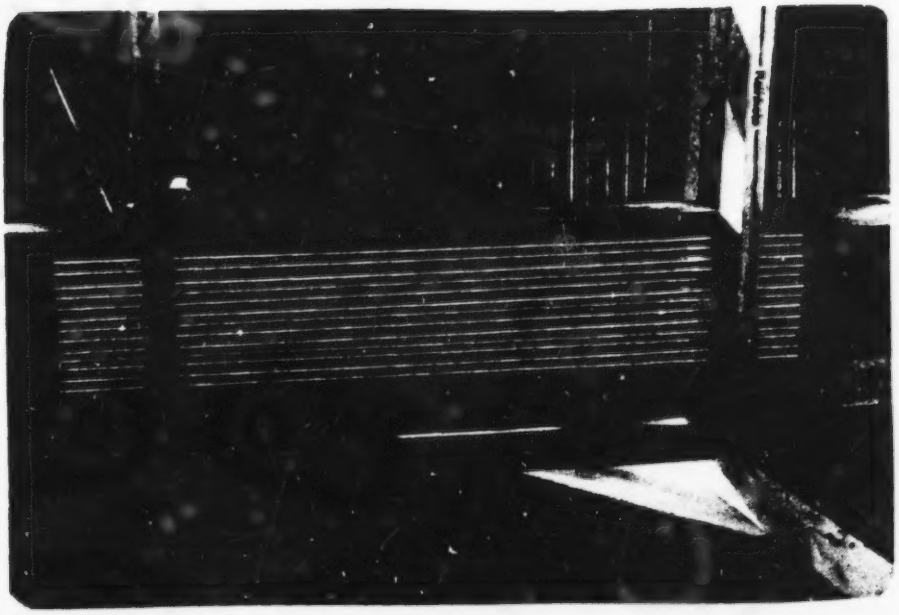


Photo #26 - squeezing of panels

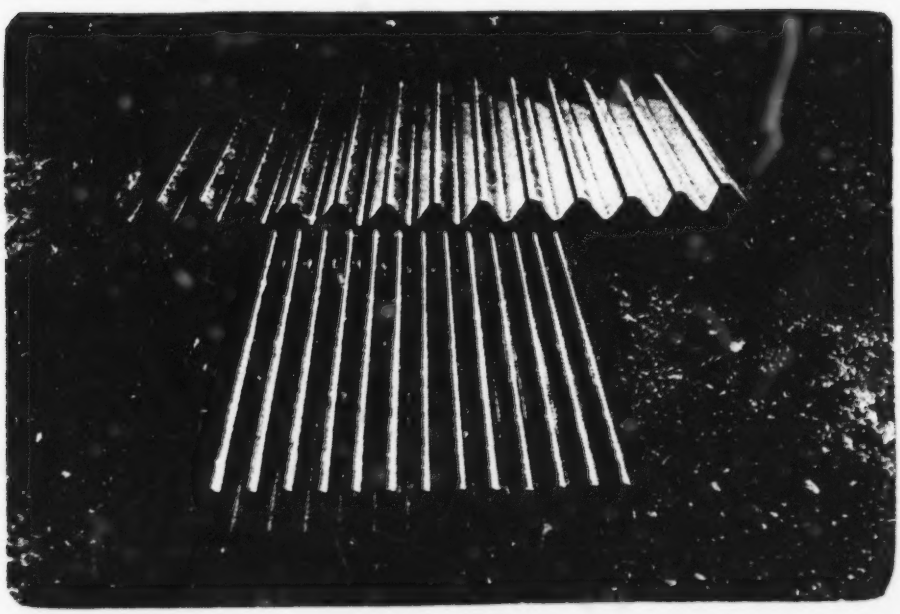


Photo #27 - Bent and squeezed panels

(i) Solar Collectors

Photo #28 - wall collectors, inside view.

(j) Shutters

The south window shutters were constructed of 3/4" spruce frame with 1/4" fir plywood sheathing on each side. The boxes were made for the window openings, the inside sheathing applied, and the R 15 insulation installed. The boxes were then put in place and shimmed to provide proper side and bottom clearance. The outer sheathing, which was large enough to lap the outside window casing, was then screwed to the boxes. A 5" wide 1/4" plywood strip was attached to the top outer side of the shutters to give improved hinge support. The hinges were attached along the edge of the 5" strip, the entire assembly was then swung open, and the shims removed. A thin plastic foam weather strip was then applied to the window casing around the perimeter of the entire group of windows. Small thumb buttons were used to keep the shutters in the closed position. The opening mechanism consisted of two polypropylene ropes with a pulley arrangement and an over centre locking lever. The other window shutters were of the same type of construction as the south shutters but were hinged along a vertical axis.

12. BUILDING CONSTRUCTION NOTES Cont.
(j) Shutters

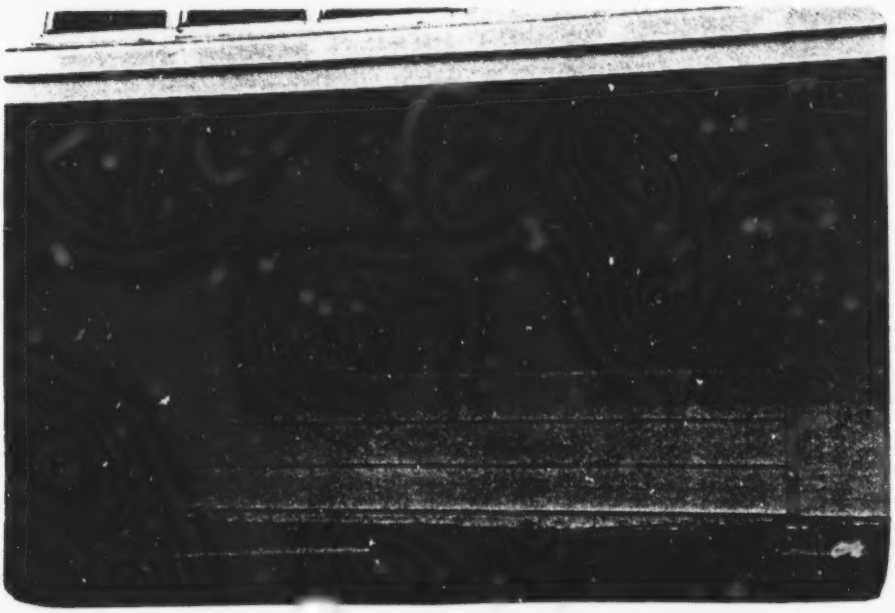


Photo #29 - Outer sheathing being applied.

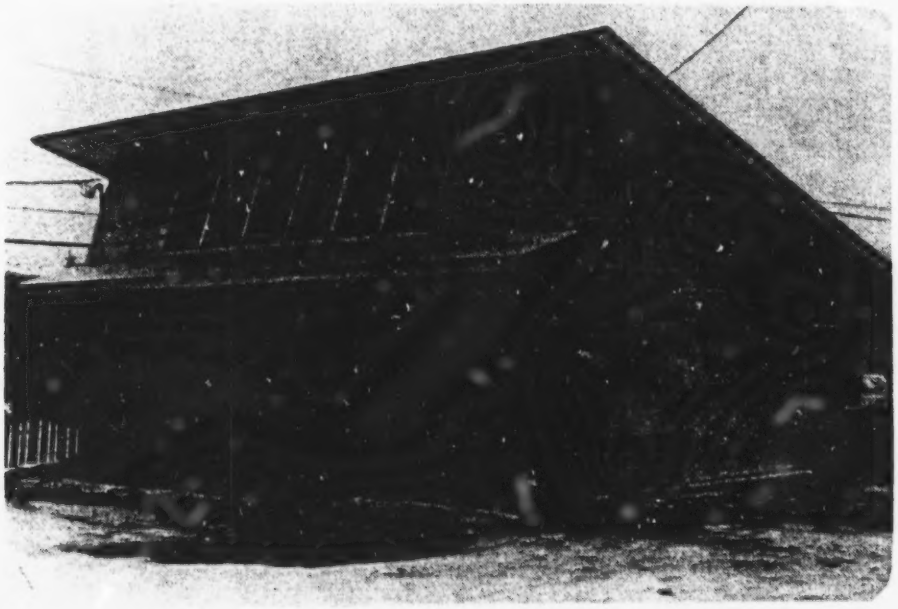


Photo #30 - Finished shutters - closed

12. BUILDING CONSTRUCTION NOTES Cont.

(j) Shutters

Photo #31 - Shutters open.

(k) Shades and Reflectors

The upper shade framework was built as part of the original rafters. The upper side was finished in the same manner as the roof of the building. The lower side was sheatehd with 1/4" hardboard, painted with a high gloss white enamel. The lower shade framework was also part of the original rafters. Additional short rafters were used both top and bottom to get the proper angle for reflection. The upper rafters were sheathed with 7/16" chipboard. Both the top and bottom were covered with 1/4" hardboard, painted with high gloss white enamel. The joints in the top surface were caulked with acoustical sealant.

With reference to the photos the 1:00 C.S.T. represents solar noon which is the time at which the sun is directly south. Lanigan is located very near the edge of the Mountain Standard Time Zone. Solar noon would be 12:00 M.S.T. (within 9 seconds), however Lanigan operates on C.S.T.

The time of 2:08 C.S.T. is the time at which the sun is located at the position of magnetic south. This was approximately the time at which the solar collectors gave the largest heat output.

During most of June and July the collectors are in total shade at solar noon. During all of December and January the collectors are in total sunshine at solar noon.

The solar energy input to the building from the forced air collectors was always much more impressive than the input from the windows, although in theory the windows should have higher efficiency. The energy impinging through the windows does not cause a rapid change in air temperature since it is absorbed into the floor for later release.

12. BUILDING CONSTRUCTION NOTES Cont.
(k) Shades and Reflectors

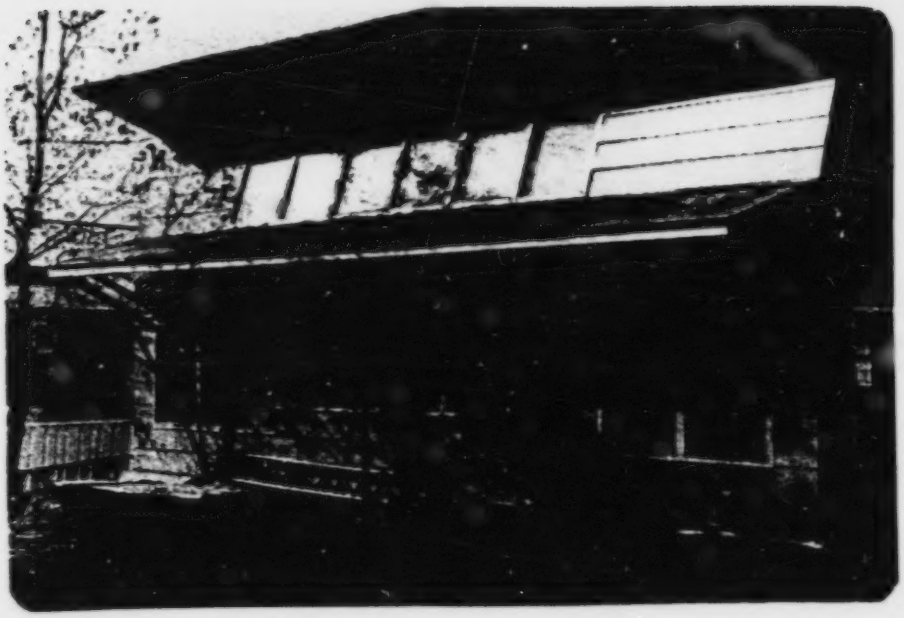


Photo 32 - Lower shade construction

Photo #33 - Shade effectiveness

12. BUILDING CONSTRUCTION NOTES Cont.

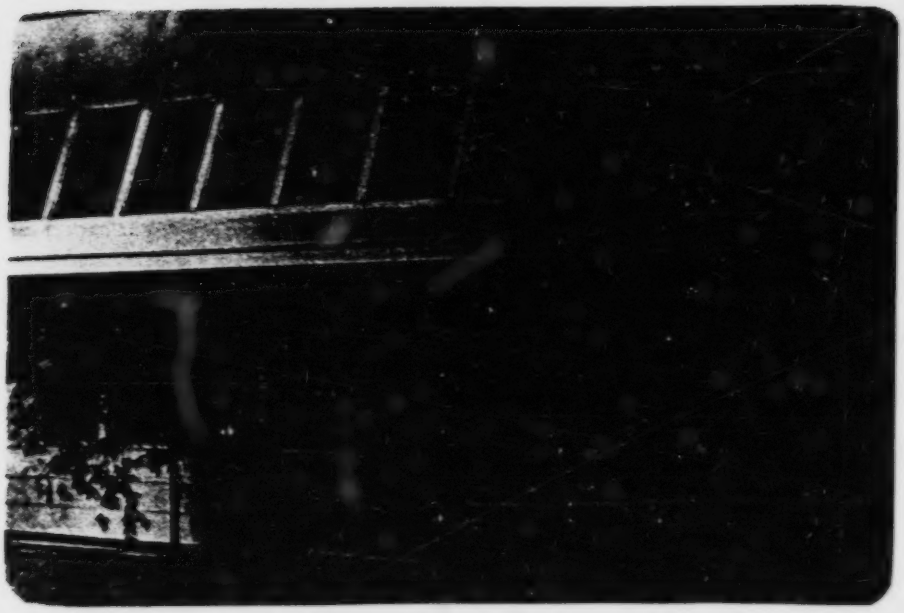


Photo #34 - Shade effectiveness

13. MONITORING EQUIPMENT AND PROBES.

The monitoring equipment consisted of the following:

One - 24 channel graph temperature recorder
Texas Instrument Multiwriter
Model FMWST6C

One -10 channel digital temperature indicator.
Doric Trendicator Model 410A

One -10 channel switch
Doric Multipoint Selector Model 405A

One -4 channel event graph recorder
Gulton Model A 208-292-4

One -Power supply
Micronta Model 228230

One -Hydrothermograph
Weather Measure Corp. Model 11311

One -Air velocity measuring instrument
Alnor Velometer Type 3002-3g

The temperature probes consisted of the following:

Probe No.	Location
1	72" below soil surface 10' outside building wall
2	36" below soil surface 10' outside building wall
3	2" below soil surface 10' outside building wall
4	72" below soil surface 1' outside building wall
5	36" below soil surface 1' outside building wall
6	2" below perimeter insulation 1' outside building wal
7	72" below soil surface 1' inside building wall
8	36" below soil surface 1' inside building wall
9	2" below soil surface 1' inside building wall
10	2" below top of concrete 1' inside building wall
11	72" below soil surface, centre of building.
12	36" below surface, centre of building.
13	2" below soil surface, centre of building.

13. MONITORING EQUIPMENT AND PROBES CONT.

Probe No.	Location
14	2" below top of concrete, centre of building.
15	Inlet air-south wall collector (west)
16	Collector panel - south wall collector (west)
17	Outlet air - south wall collector (west)
18	Inlet air - upper collector
19	Collector panel - upper collector
20	Outlet air - upper collector
21	Attic air - 2" above insulation
22	Air inlet - south wall collector (east)
23	Collector panel - south wall collector (east)
24	Air outlet - south wall collector (east)
1A	Glass - south window
2A	Inside air - 1" from south window
3A	Outlet air - heat exchanger
4A	2" above floor - N.W. corner
5A	48" above floor - N.W. corner
6A	2" below ceiling - N.W. corner
7A	Outdoor air - North
8A	Glass - north window
9A	Inside air - 1" from north window
10A	Air inlet - east collector
11A	Air outlet - east collector
12A	Collector panel - east collector
13A	2" above floor - N.E. corner
14A	48" above floor - N.E. corner
15A	2" below ceiling - N.E. corner
16A	2" above floor - S.W. corner

13. MONITORING EQUIPMENT AND PROBES Cont.

The event recorder was connected as follows:

Channel No.	Connection
1	electric furnace
2	south wall collector - west
3	upper collector
4	south wall collector - east

The hydrothermograph was located 2' from the inside of the west wall, and 6' from the inside of the south wall at a height of 3' above the floor.

14. OPERATING NOTES

(a) Doors

The walk-in doors have performed well and have proved durable and trouble-free. As discussed in the building notes air vents of 1½" diameter were installed to allow air movement as the doors were opened. Without the vents it was possible to close both doors since the pressure increase caused by the last door closure caused the seals to partially collapse and release the air. However on attempting to open the doors, the partial vacuum created between the doors caused the seals to swell and seal so well that it was almost impossible to open the doors. The vents were designed to open prior to door opening, and to close after door closing.

Automotive type wax was used on the seals to improve durability and to lower the coefficient of friction. The door opening was painted in gloss white. The amount of force required to close the doors was such that a wedge type lever closure was required. Opening of the doors is relatively easy provided time is allowed for air movement through the vents.

If the door opening becomes wet, as has happened on some occasions in the spring time, then the force required to open the doors increases by a factor of several times. The most probable cause for the increase is the viscous forces of the water film. The frequency of this occurance has been low and does not present a serious problem.

There has been no apparent wear of the vinyl seal surface. There has been concern over possible damage caused by metal chips from drilling machines or lathes. Care has been taken to reduce this hazard and no damage has been detected to date. Sand or gravel has little or no effect on the performance of this type of seal. The vinyl is simply depressed and moulds itself around the particle, with no loss of seal effectiveness.

The vehicle doors have also proven to be very satisfactory. The double seals, closure system, and curved corner design have met expectations.

(b) Upper Collectors - There was a leakage problem encountered in the operation of this system. The air for the upper collectors is supplied by a centrifugal blower installed in the building. This blower takes filtered air from the building and forces it into one end of the upper collector ductwork. The air then moves through the ductwork and down into the other end of the building. Pressure operated doors are installed at each end of the ductwork. The result of this design is that the ductwork air is under a small positive pressure. When the system is operating air movement into the building is noticed is a door vent is opened. The location of the leak has not been determined. It may be a distributed leak caused by many small imperfections in the accoustical sealant, or a concentrated leak caused by the omission of sealant from some joint. It is known that one section of the inner glazing is cracked. The crack however has not separated and appears to not be the major source of leakage.

The ductwork was constructed primarily of 1/4" hardboard with smooth side inward in order to reduce air friction. There

14. OPERATING NOTES Cont.
(b) Upper Collectors

was a considerable odor produced by the hardboard when it was at elevated temperatures. The odor decreased with time, and by the second heating season was not detectable. During the first few months of operation the odor would not have been acceptable for a dwelling. The odor was caused by formaldehyde being released from the adhesives in the hardboard.

The upper collectors were inclined at an angle of 19° from the vertical. It was noted that the glazing required more frequent cleaning than vertical glazing. This problem was most evident during the spring and fall when the dust levels were higher. Ropes are permanently attached to the building to assist in the cleaning operation There was no problem with snow accumulation in the winter. Any snow which did fall on the glass was removed quickly by wind action.

The operation of the blower, pressure sensitive doors, and thermostat system proved satisfactory.

(c) Wall Collectors

The original wall collectors consisted of two types. The west part of the south wall was fitted with natural flow units, while the east part of the south wall was fitted with forced flow units. After conducting efficiency tests the natural flow units were converted to the forced flow type. The east wall was also fitted with a forced flow type of collector.

It was observed that the south wall collectors did not usually get warm enough to start operating until about 11:30 C.S.T. This observation was made during the months of December and January, on bright sunny days. This was due in part to the magnetic orientation of the building, resulting in the south wall facing 17 degrees west of true south. The east wall collector would turn on by about 9:30 under the same sun conditions.

The east wall collector is not shaded and consequently reaches a very high temperature in the forenoon of the summer days, when the fan is in the off position. The temperatures are shown in appendix "B". An outside non-insulated shutter, or sun shade, will be installed during the spring of 1983 to eliminate this problem.

The wall collectors have proven to be trouble-free and have performed to expectations. Compared to the upper collectors they offer the following advantages:

1) They are easily accessible for adjustment of internal thermostats.

2) The glazing, being vertical, tends to require less cleaning, and is also easier to clean.

3) The construction of the ductwork is simpler.

14. OPERATING NOTES Cont.

(d) Venting System

Because of the tightness of the building, and the lack of an air to air heat exchanger the building air tends to become odour contaminated very easily. If a piece of lumber previously painted several weeks ago, is brought into the building. The paint odour becomes detectable within a few hours. The low infiltration rate of .16 air changes per hour must be supplemented by forced ventilation during painting or welding operations. The building is also forced ventilated after being unused for some days.

The low speed, large diameter exhaust fan has proven very satisfactory with regard to low noise level and high ventilation rate. The adjustable balanced doors on the fan opening have proven desirable. With cold outdoor temperatures low ventilation rates can be used for light welding operations. Under these conditions the doors are nearly closed and the fan noise is negligible. On the other hand the doors can be fully opened and the building air can be fully exchanged in less than a minute. The exhaust fan is near one end of the building, just above the welding bench. It opens to take air from its upper side. The inlet air opening is at the other extreme end of the building. Thus welding fumes are drawn directly into the exhaust fan, and also fast air exchanges can take place due to the end to end air flow. The exhaust fan has also been used for cooling in the summer. After a prolonged period of hot summer weather with temperatures over 90°F. the interior building temperatures may get to the high seventies. Running the fan during the night time is effective in cooling the building.

In the original building project it was planned to construct and install an air to air heat exchanger for humidity control as well as air quality control. The planed design for the heat exchanger was similar to a unit designed and tested at the University of Saskatchewan. Before construction was begun it was discovered that certain operational problems had been encountered with the design. As the entire air to air heat exchanger requirements were studied and the available products investigated it was discovered that many units had either low efficiencies, or defrost problems in prairie winter conditions. Consequently an air to air heat exchanger has been designed with a view to elliviating these two problems. It is anticipated that a unit will be constructed and installed in this building in 1984. In a workshop the exhaust fan system is still required even if an air to air heat exchanger is used.

(e) Shades

The shades have proven desirable for two main reasons:
1) They have kept collector temperatures low in the summer when the fans are turned off. Lower temperatures give extended collector life, reduce thermal strains, and also reduce fire hazard. A well insulated collector, inclined from the vertical, can present a fire hazard in very hot summer weather, if constructed of combustable material. After long periods of time at elevated temperatures, the kindling temperature of certain materials may be reduced. If the heat removal system is not functioning then the collector assembly may reach the kindling temperature.

14. OPERATING NOTES Cont.
(e) Shades

2) The shades have helped to reduce summer time interior building temperatures. Many visitors entering the building in hot summer weather think the building is air conditioned. For short duration hot periods the building interior temperature is often 15°F to 20°F. cooler than the exterior air temperature even in mid or late afternoon. The high degree of insulation is of course useful in keeping summer interior temperatures low.

15. MONITORING RESULTS AND CONCLUSIONS

(a) Air Infiltration

Air infiltration tests were done by the National Research Council, Saskatoon Branch in August, 1982. The report on this test is in Appendix "C" of this report. The ducts refered to in this report are the automatic pressure activated sealing doors located in the ductwork to the upper solar collector system. These doors open with a pressure increase in the building, and thus were open when the reading of 1.49 air changes per hour was obtained. The reason for the higher air infiltration figure with the vents in the automatic position was the fact that there was a leak in the upper ductwork system as discussed earlier in this report. The more meaningful test was the first one listed in which the sealing doors were in the manually closed position. The following table will assist in putting the test results in perspective:

STRUCTURE	AIR CHANGES PER HOUR AT 50 PA.
Pre 1945 houses	10.4
1946-60 houses	4.6
1961-80 houses	3.6
Special structures	1.5
Best building tested by NRC to date	.37
This building	.16

This test confirms the effectiveness of the type of sealing used on the vapour barrier and around the building openings.

(b) Infra-Red Heat Loss Tests

A thermographic survey of the building was done by Thermal Focus Incoporated, of Saskatoon, on the night of February 12th-13th, 1982. The report on these tests is included in Appendix "C" of this report. With regard to this report the following comments may be made:

1. Comment is made in the introduction (a) regarding corner anomalies due primarily to thermal bridging at wall to wall junctures. The inner wall and out outer wall maintain their 5" spacing at the corners and there are no wood ties in the corner areas. The entire corner region is insulated in the same manner as the balance of the wall. The anomalies may be due to the double conduction path existing at the corners. Thermal Focus Incorporated was not aware of the corner construction details at the time of the test.

2. The building specifications indicate a gas-fired back-up heating system. This is a misprint as the back-up heating system is electric.

3. The building floor plan orientation is magnetic north rather than true north.

(c) Effect of Ceiling Fan on Interior Air Temperatures
Data-Page B-1

As the data indicates the ceiling fan has a marked effect on the air temperature near the floor, reducing a difference of 11.9 C between ceiling and floor to a difference of .9 C.

The fan has little effect on air temperatures near the ceiling compared to the 48" level. It is probable that the ceiling air temperatures would be more effected by the fan, if the building height were greater.

(d) Solar Reflectors Data-Page B-2

The solar reflectors were tested on March 8th, 1982 and March 10th, 1982. The sky condition was clear except for some very, very thin high cirrus from 12:30 to 13:00 on March 8th. The solar reflectors were operating on March 8th, whereas they were covered with black plastic polyethylene on March 10th, and thus not operative. It was intended to do the tests earlier in the winter but there had not been two sunny days within a day or two of each other until the above dates. The reflectors are designed to be of most benefit during the months of December and January.

The following chart illustrates the performance of the upper collectors by comparing their temperature to the East and West collectors in the South wall. All air duct circulation fans were in the manual run position for all tests. One would expect the upper collector temperature to be relatively higher on March 8th, since the reflectors were designed to assist the upper solar collector. The figure suggest the upper collector temperatures were actually lower with the reflectors in the operating mode. There is no explanation for the reversal of temperatures, at this time. The polyethylene used to cover the reflecting surface was 6 mil black and it was not a flat black, but rather a medium gloss, so some reflection would occur from it. It was however, wrinkled when in place, and most reflections would consequently not strike the upper collector.

The data suggests that the reflectors are not effective, however the tests were not done at the optimum time of the year. The solar rays from the reflectors were thus striking the collectors at a high angle of incidence, which would reduce their effect. More tests were required to accurately determine the value of these reflectors. If shades are constructed for the lower collectors, then they must have an upper sheathing for moisture run-off. Making this sheathing act as a reflecting surface adds neglegible cost.

Collector Comparisons

March 8/82 - reflectors operating, Outside air temperature - 14 C..

March 10/82 - reflectors not operating, Outside air temperature - 16 C..

E - East collector plate temperature.

W - West collector plate temperature.

U - Upper collector plate temperature.

	March 8			March 10		
Time	U/E	U/W	$\frac{U/E+U/w}{2}$	U/E	U/W	$\frac{U/E+U/W}{2}$
12:30	.854	.842	.848	.858	.887	.873
12:45	.846	.799	.822	.856	.854	.854
13:00	.841	.787	.814	.853	.834	.844
13:15	.823	.757	.790	.851	.801	.826
13:30	.834	.769	.801	.847	.800	.824
13:45	.826	.779	.802	.834	.789	.812
14:00	.823	.786	.805	.823	.792	.808
14:15	.828	.794	.811	.826	.802	.814
14:30	.828	.808	.818	.828	.815	.822
14:45	.831	.828	.830	.833	.843	.838
15:00	.842	.887	.864	.844	.910	.877
15:15	.856	.976	.916	.852	.976	.914
15:30	.863	.969	.916	.861	.995	.928

(e) Sun Shades Data-Page B-4

As illustrated in the data the East unshaded collector plate rises to a temperature over the boiling point of water while the South shaded collector plate reached a temperature of only 56 C. Both temperature readings were with the circulation fans off. The peak temperature of each collector plate is delayed somewhat because of the heat storage capacity of the collector ductwork. The time of peak temperature therefor does not coincide with the time of maximum solar heat gain. The time of maximum heat input to the building varies considerably with the season for the East collector. The upper collector however gives maximum heat input to the building at approximately 14:00 C.S.T. regardless of the time of year.

(f) Solar Collector Efficiencies Data-Page B-6

The following chart illustrates the thermal efficiencies of the three collector systems as well as the figures which were used to calculate them.

Time	South(West)	Upper	South(East)
	*Output in B.T.U/HR		
12:30	772	8696	3541
12:45	1065	9080	2791
13:00	1270	8920	2880
Average	1036	8899	3071
Area (Ft^2)	15.83	57.5	15.83
B.T.U./Ft^2	65.45	154.8	194.0
**Solar input(B.T.U./Ft^2/Hr	345.0	383.9	345.0
Efficiency (%)	19	40	56

*As determined from raw data of velocities, temperature differences, and air densities.

** As determined theoretically from sun angles and sky conditions.

The variation in the collector output figures suggest that errors in measurements may be rather high. It is evident however that the natural flow system has a much lower efficiency than the forced flow type. The lower efficiency of the upper collector system may be due to a leak in the upper ductwork, as discussed earlier in this report.

(g) Solar Collector Systems Comparisons

It was anticipated that the building could be operated first on one system only, then a day or two later switched over to another system. A comparison of systems could then be made under actual operating conditions. By running the tests within a day or two of each other there would be very little change caused by sun angles. It was not possible to run tests close together in time since two or three consecutive days of clear sky conditions did not occur. It was also realized that outdoor temperature conditions would fluctuate from day to day and effect results. The following conclusions are therefor subjective only and are not supported by data.

The South facing windows were the least impressive means of collecting solar energy, even though they should have a higher thermal efficiency than either of the forced air flow systems. There are two reasons for the seemingly low performance:

1) The solar energy coming through the windows warms the floor and other objects which it strikes, but does not directly warm the air in the building. The heated objects do warm the air but at a later time, and at a rather slow rate. This solar energy thus reduces the night time cooling rate, but gives very little daytime temperature rise.

2) In order to get solar gain through the windows the outside shutters must be open. This then increases the building heat loss since the windows alone have an R value of 5 to 6, whereas the window with shutters down has an R value of approximately 21. The difference in heat loss between window only, and window with shutters down is approximately 14 B.T.U./Ft^2/H (using R values of 5 and 21 and a ΔT of $80^{\circ}F$.). When compared to the heat input through the window of 200 to 300 B.T.U./Ft^2/Hr the figure of 14 B.T.U./Ft^2/Hr is rather insignificant, assuming that the shutters are open only during the collection of solar energy at the rates mentioned above. Reason number two therefor is not a major reason for the apparent low performance.

Both the south wall collectors and the upper collectors give impressive results when operating. If the ceiling fan is not running then interior air temperatures rise quickly, even with cold exterior conditions. Use of the ceiling fan reduces the impressiveness, but does result in better overall performance. After the first of March solar gain from the forced flow systems is sufficient to keep the building at a

15. MONITORING RESULTS AND CONCLUSIONS Cont.
(g) Solar Collector Systems Comparisons Cont.

comfortable working temperature (55°F) if there are clear skies two out of each three to four days.

(h) Solar Heat Vs Back-up Heat -Data Page B-8

For the test period of Feb. 23/82 to March 23/82 57% of the heating load was supplied by solar and 43% by electric back-up. The relatively low percentage of solar heat was due in part to the evening demand for heat to maintain a working temperature of 55 to 60°F. Had the objective been to only keep the building from freezing, the percentage of electric would have been several percentage points lower. It is interesting to note that during the test period of 28 days, there were 10 days in which there was no solar heat gain.

During the 1982-83 heating season the percentage of solar heating was much lower than during the test period. The monitoring equipment was not in use during the 1982-83 heating season, so there is no data from which to calculate heat gains. The time of operation of the solar collectors was estimated however and the following results concluded:

Total Hours of Solar Collector Operation

Dec. 15/82 to Jan. 15/83 - less than 2 hours

Jan. 15/83 to Feb. 15/83 - 10 hours

The 1982/83 heating season had a higher than average percentage of cloud cover.

The average monthly heat gain for March, using the average between a collector angle of vertical and 18° from vertical (see Table 3) would be 29,709 B.T.U./Ft^2. Correcting this figure for the 28 day test period as opposed to the 31 days in March gives 26,834 B.T.U./Ft^2 as the yearly average energy expected for the test period, at 100% efficiency. A further correction for the test period being partly in February may be applied as follows:

26,843 - 5/28 (26,843 - 22,958) which then results in a figure of 26,147 B.T.U./Ft^2.

The total collecting area during the test period is 28.3 Ft^2 (windows) + 38.52 Ft^2 (south) + 57.5 Ft^2(upper) which gives 124.12 Ft^2. Using an average collector efficiency of 50% the expected gain of the system would be: 26,147 x 124.12 x .50 giving 1,622,683 B.T.U. Weather records from the Wynyard weather station for the test period indicate that the amount of sunshine was 86% of long term average. The expected gain would then be 1,622,683 x .86 giving 1,395,507 B.T.U. The actual solar

15. MONITORING RESULTS AND CONCLUSIONS Cont.
Total Hours of Solar Collector Operation

heat collected was 748,865 B.T.U. or 54% of expected. The low percentage is partly due to the collectors inability to turn on under low radiation levels, which reduces the overall average efficiency. These results suggest that for design purposes a figure of .50 x .54 or 27% of long term average can be used to predict the amount of energy reaching the building, under typical operating conditions.

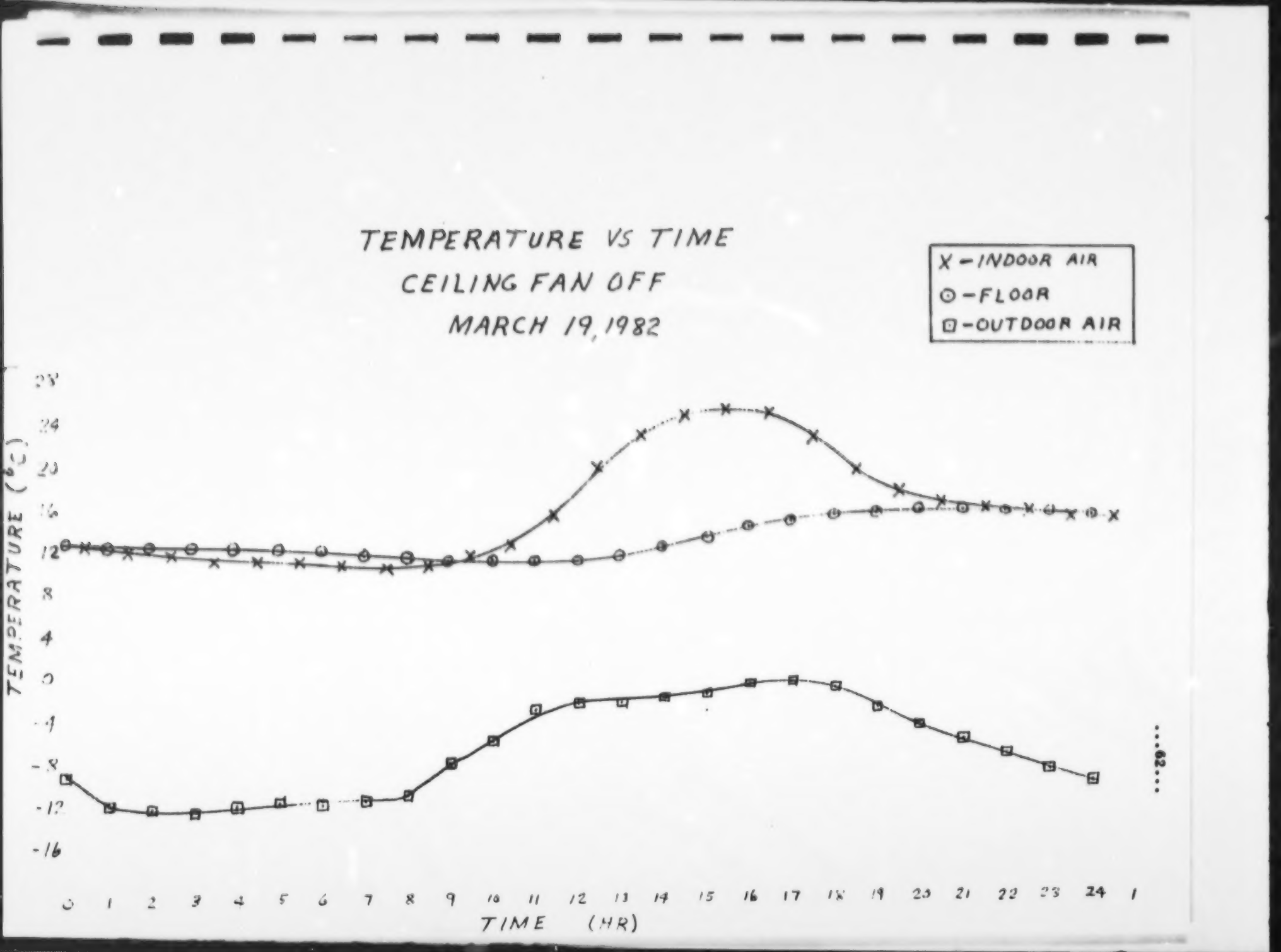
(i) Floor Heat Storage Vs Ceiling Fan Operation - Data Page B-18

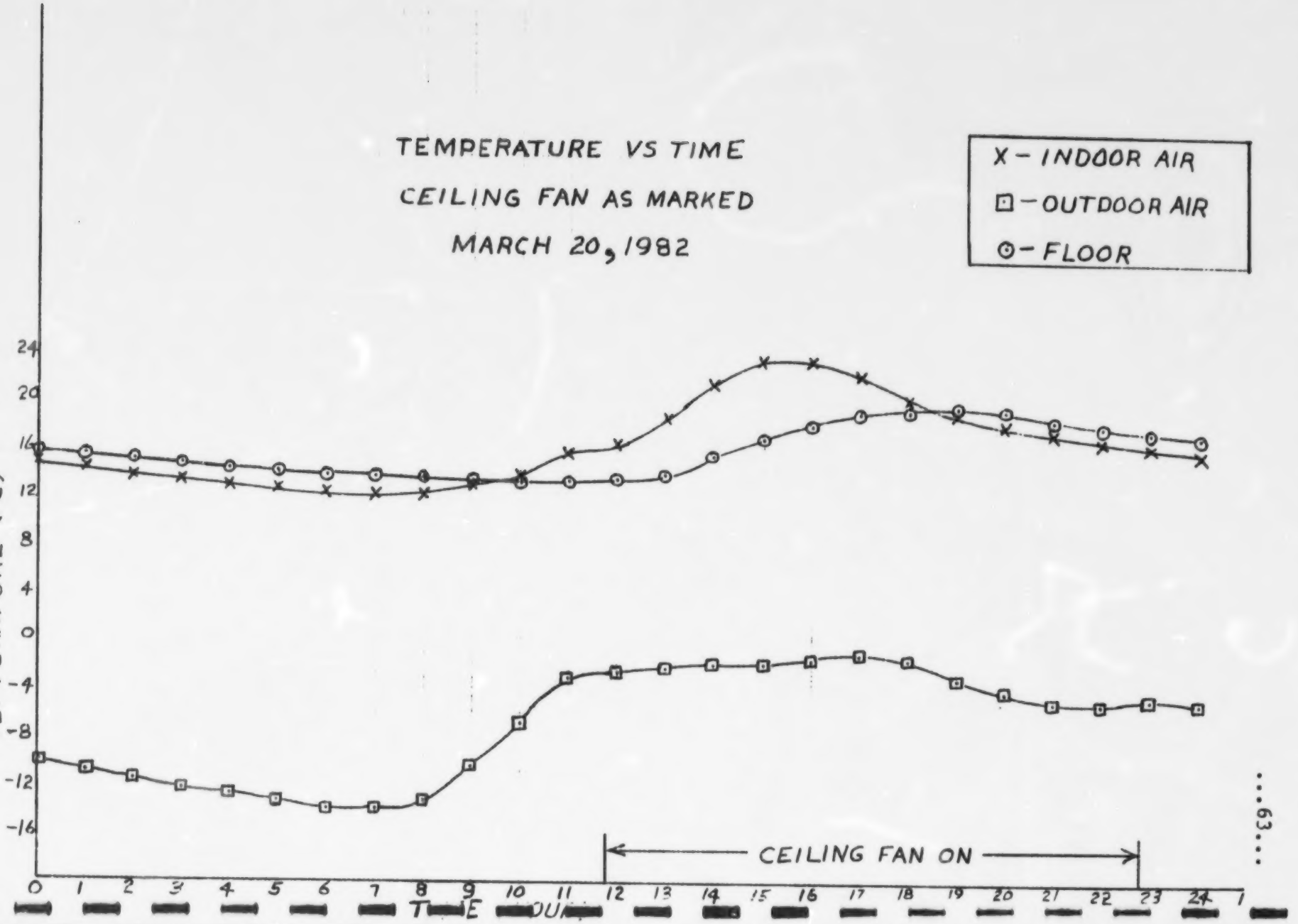
As shown in the accompaning graphs the floor does act as a heat sink, and such action is improved by the operation of the ceiling fan.

As indicated the air temperature swing is reduced and the floor temperature swing is increased by use of the ceiling fan. The following chart illustrates these points.

Time	Fan	Air ΔT	Floor ΔT	T(air)-T(floor)
8:00 to 24:00	off	15		
8:00 to 24:00	on	11		
12:00 to 16:00	off		3	
12:00 to 16:00	on		4.7	
15:00	off			11.7
15:00	on			6.1

The tests were done on clear days with solar as the main source of heat. The electric backup heating system was set to prevent temperatures from falling below 8°C.


TEMPERATURE VS TIME
CEILING FAN OFF
MARCH 19, 1982
X - INDOOR AIR
⊙ - FLOOR
⊡ - OUTDOOR AIR
TEMPERATURE (°C)
TIME (HR)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1
-16
-12
-8
-4
0
4
8
12
16
20
24
28
....62....


TEMPERATURE VS TIME
CEILING FAN AS MARKED
MARCH 20, 1982
X - INDOOR AIR
□ - OUTDOOR AIR
⊙ - FLOOR
24
20
16
12
8
4
0
-4
-8
-12
-16
CEILING FAN ON
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1
TIME (HOUR)

15. MONITORING RESULTS AND CONCLUSIONS Cont.

(j) Heating Effect of Lights

The calculated building heat loss rate of 1.271 KW at -30°F outside temperature and 65°F inside temperature would suggest that lights alone should be sufficient to heat the building. A test was done on March 18/83 and March 19/83 with regard to this possibility.

March 18/83 22:00 Power reading 4322.2 KWH
All lights turned on (18 - 8 ft. tubes, 6 - 4 ft. tubes.)
Air temperature 58°F.

March 19/83 9:15 Power reading 4343.0 KWH
Air Temperature 56°F.

Power consumed 20.8 KWH in 11 hrs. 15 min., for a rate of 1.85 KW. Average outside air temperature for the test period was -2°F.

The calculated heat loss rate at -2°F. is .789 KW. Heating with lights is thus rather inefficient. The two most probable reasons for the low efficiency are (1) the lights increase the ceiling temperature and therefore the building heat loss rate, and (2) some of the light energy shines out through the windows and is absorbed by the window shutters. Most of this energy is then lost to the outside air.

(k) Cool Down Rate Tests

Two separate tests are done, one on March 20/83 and one on March 21/83. The monitoring equipment had been removed by this date, so no detailed data is available. On March 20 the solar collectors had been running at about 50% capacity during the afternoon. The ceiling fan was operated from 12:00 to 18:00. The interior air temperature has risen to a maximum of 70°F. Slow air venting had taken place (by exhaust fan) from 20:00 to 22:00. An interior air temperature reading of 55°F was recorded at 22:00, at which time the electric furnace and all lights were turned off. At 9:00 the next morning (March 20) the interior air temperature was recorded at 55°F. The outside air temperature had been at an average of 0°F. for the test period.

The zero temperature drop had occured as a result of heat transfer from the floor and other building materials during the night. The 22:00 evening air temperature had been depressed below the floor and other building material by the slow air venting which had taken place.

The second test occured on March 21/83. The solar collectors had been running at about 50% capacity during the day. The ceiling fan had been running during part of the day. No air venting had taken place. The interior air temperature was recorded at 65°F. at 22:00 at which time the electric furnace and all lights were turned off. At 8:30 the next morning the interior air temperature

15. MONITORING RESULTS AND CONCLUSIONS Cont.
(k) Cool Down Rate Tests cont.

was recorded at 56°F. The average overnight outside air temperature was -8°F.

These tests do indicate the general type of performance one can expect from a super-insulated structure.

(l) Window Performance - Data Page B-20

Some condensation occured in the window air spaces, but under unexpected conditions. One would expect condensation to occur after an outside air temperature drop, especially in high humidity conditions. This did not occur. However condensation did appear during the first sunny warm days in February. Most of the condensation would clear during the night. There was no correlation between the amount of condensation and the size of the window vent holes.

The most probable cause for the condensation is frozen moisture in the wall cavity insulation, just below the windows. When the sun shines on warm days some of this moisture melts and diffuses into the window air space, through the vent holes. The glass is cooler than the wall cavity so condensation occurs.

The moisture in the wall cavity probably comes from moisture condensation on the inner surface of the inner glass. During the early part of the winter of 1981-82 the outside window shutters had not yet been installed. There was also no air to air heat exchanger for humidity control. The inside air temperature was allowed to drop to approximately 8°C. at night. This low temperature, along with relative humidities of up to 70% resulted in severe condensation and frost on the inner surface of the inner glass. Some of this moisture probably penetrated the plywood window frame and entered the wall cavity insulation, where it remained frozen until the warm sunny days of February. It is also possible that there was some frost build-up on the portion of the concrete floor situated at the bottom of the wall cavity, toward the outside edge. There would be some diffusion of moisture through this concrete from the inside air and also from the soil. If this rate of moisture movement was faster than the sublimation rate at the concrete surface then frost would accumulate.

During the 1982-83 heating season the window shutters were kept closed for almost the entire season. The air to air heat exchanger was not installed, however the relative humidity was kept at about 40% due to the concrete floor having been painted. There was no condensation in the windows during this time.

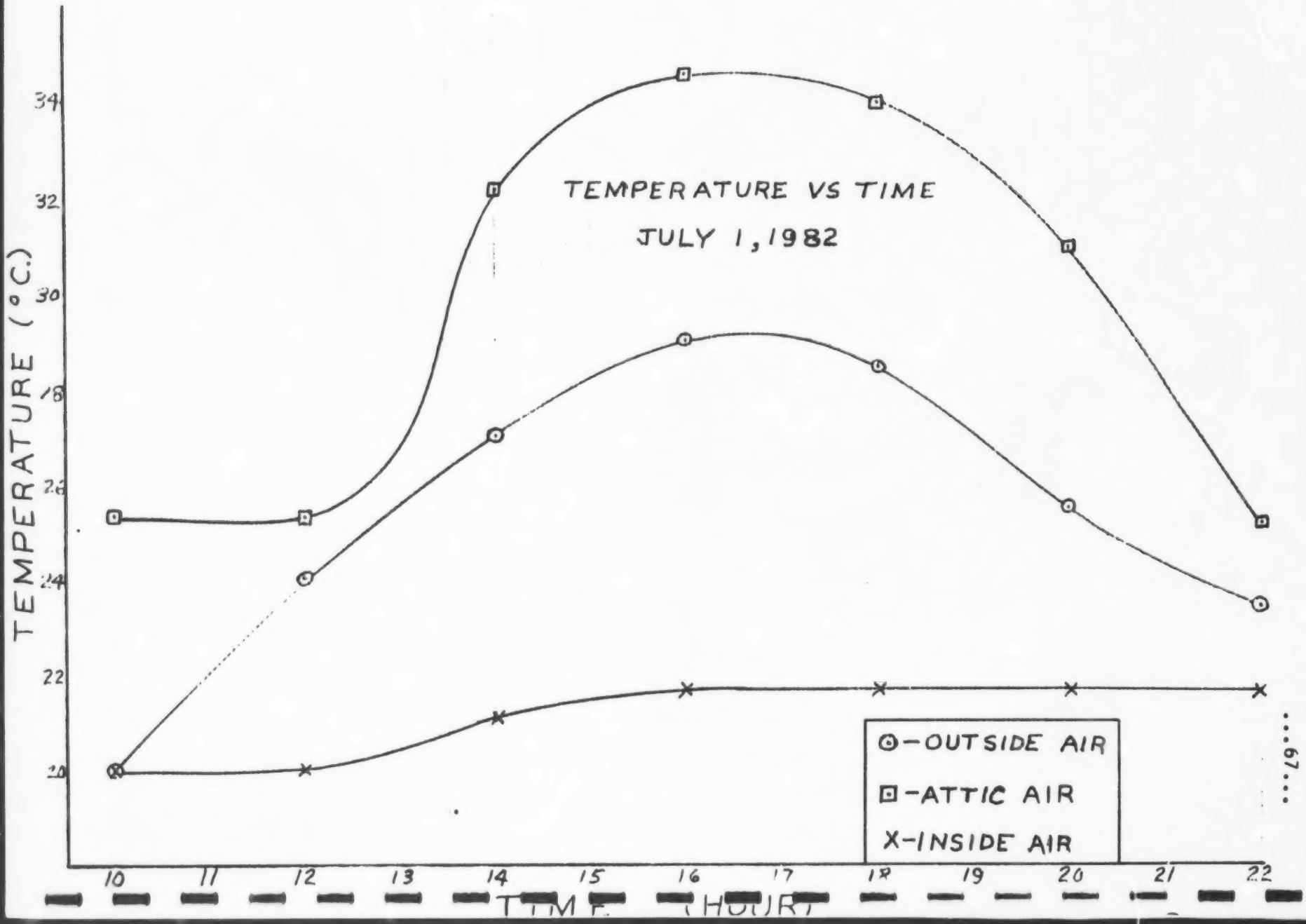
The R values of the three glaze and four glaze windows was measured to be 5.3 and 7.0 respectively. The wide air space window design does give increased R values however shutters give a much greater gain in R value.

15. MONITORING RESULTS AND CONCLUSIONS cont.
(m) Summer Operation - Data Page B-21

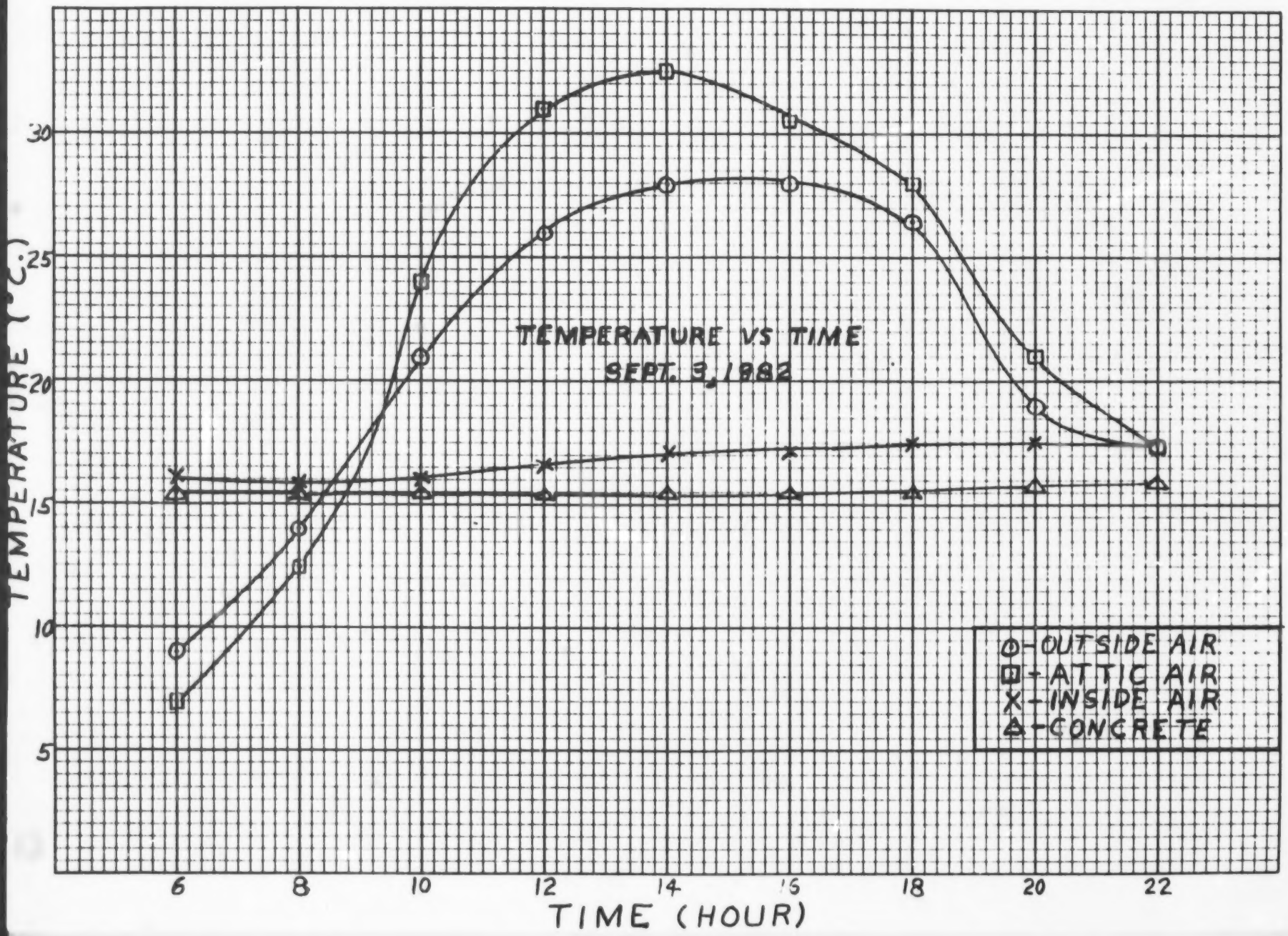
Summer operation has proven to be entirely satisfactory. The interior air temperatures have remained well within comfortable limits. The accompaning graph for July 1/82 illustrates the conditions which occur on a typical warm sunny summer day. All collectors were off and all window shutters were closed.

The first graph for Sept. 3/82 illustrates the modulating effect of the concrete floor on interior air temperature.

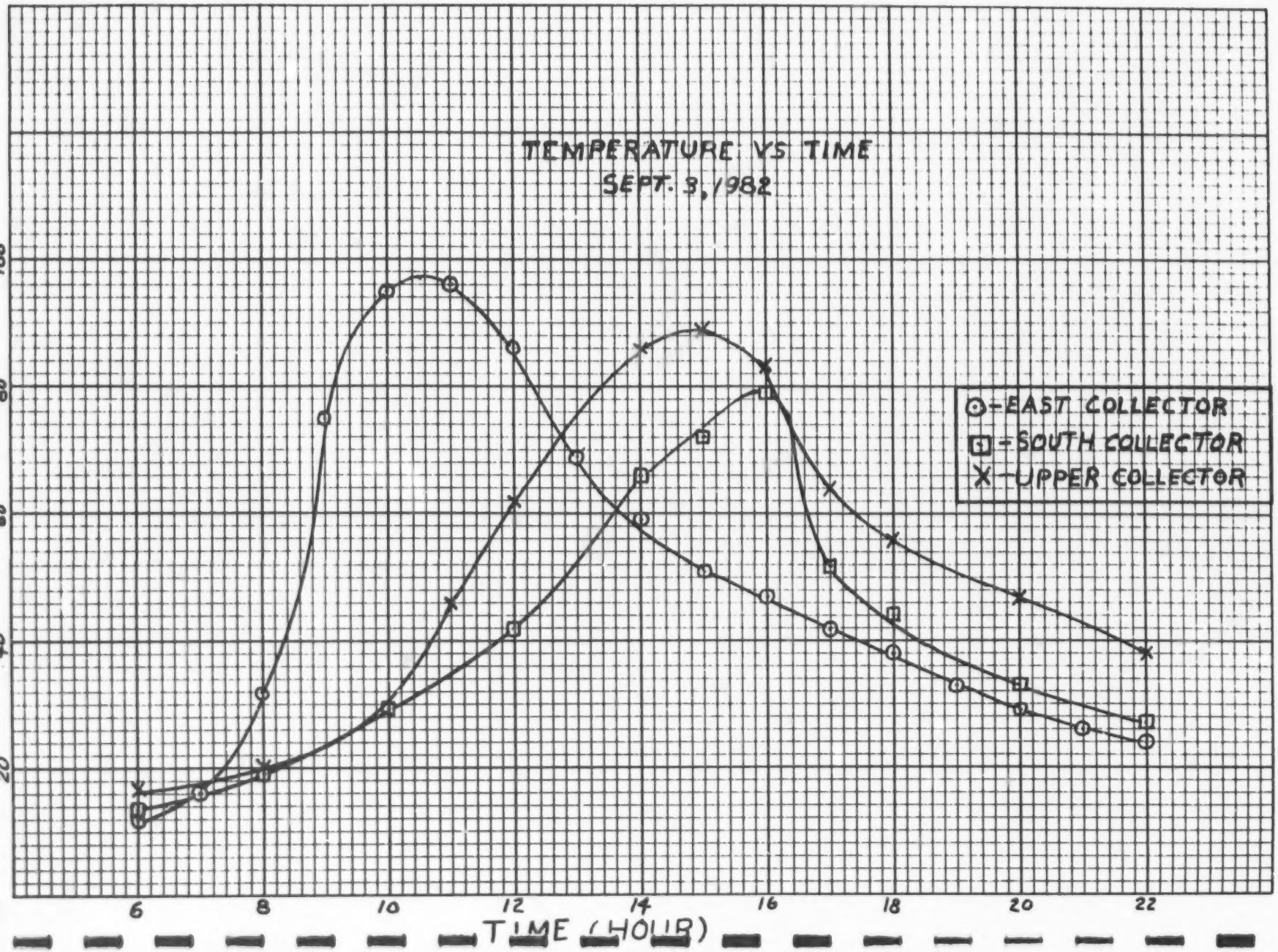
The second graph for Sept. 3/82 indicates the collector plate temperatures under a fully sunny day, with all fans off. The maximum collector temperatures do not coincide with the time of maximum solar heat gain since the collectors were not discharging their heat. It is evident that the East facing collector is capable of giving an earlier heat input to the building, than the south facing collectors. Directions referred to are magnetic and therefore south is 17^{o} west of true south.


TEMPERATURE VS TIME
JULY 1, 1982
TEMPERATURE (°C.)
34
32
30
18
24
22
20
10
11
12
13
14
15
16
17
18
19
20
21
22
TIME (HOUR)
⊙-OUTSIDE AIR
⊡-ATTIC AIR
X-INSIDE AIR

C-6453A
10 X 10 TO THE INCH
MADE IN CANADA
Stark



C-6453A
10 X 10 TO THE INCH
MADE IN CANADA



15. MONITORING RESULTS AND CONCLUSIONS Cont.

(n) Attic Ventilation

Originally it was planned to determine if reduced attic ventilation could be used in super-sealed buildings. In a well sealed building little moisture is diffusing into the attic space, therefore little air movement should be required to prevent moisture saturation of the air. This building was designed with the CMHC recommended ventilation value of 1 ft^2/600 ft^2 of floor area. With high ceiling insulation value such as used in this building, the heat retaining value is almost all in the insulation. This fact suggests that even with a sealed attic the heat loss through the ceiling would not be reduced significantly. In this building the attic air temperature at a point 2" above the insulation is within 0.5°C of the outside air temperature, with outdoor temperatures of -30.0 °C. In view of these findings no testing was done on variable rates of ventilation.

(o) Humidity Control

The relative humidity in the building was very high during the 1981-82 heating season, with figures of 65% to 70% at an air temperature of 55°F. being typical. As discussed earlier in this report, the air to air heat exchanger was not installed. There were high frost levels on the inside window glass since the outside window shutters were not installed until late in the season.

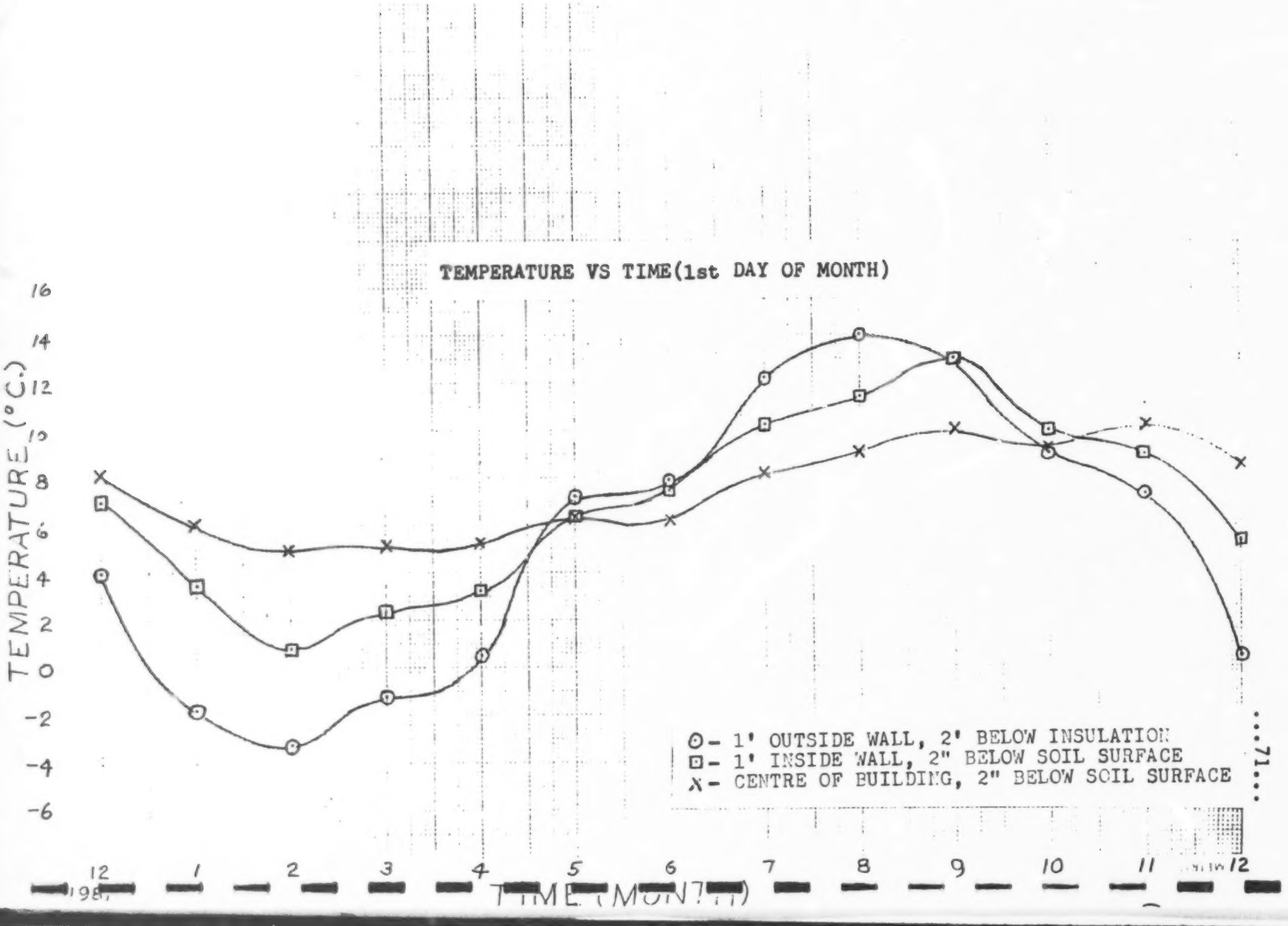
The concrete floor was coated with an oil based paint on Dec. 9/82. The coating had a marked effect on the relative humidity reducing it to approximately 40% at interior air temperatures of 55° F. The degree of the effect was surprising since the floor appeared perfectly dry. There was no indication of moisture even under large metal plates, or large sheets of cardboard stored on the floor. It is probable that the effect of sealing the floor is high because of the tightly sealed building.

A rapid relative humidity increase of 5% to 15% was noted when two or more persons worked in the building. It is probable therefore that in a dwelling with a similar air infiltration rate (.16 air changes per hour) humidity reduction would be necessary.

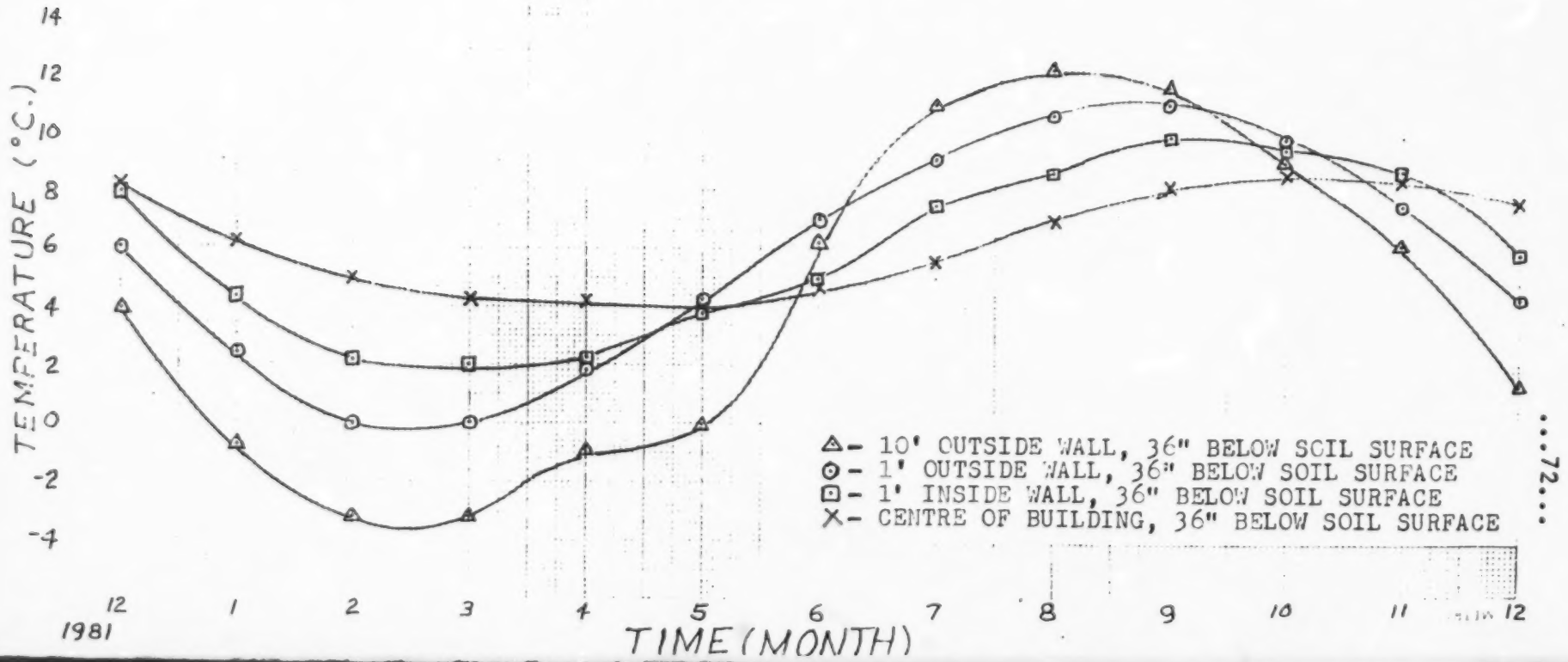
(p) Soil Temperatures - Data Page B-24

During the design of this building some difficulty was experienced in obtaining soil design temperatures and the effect of the building on these temperatures. It was decided therefore to incorporate these tests with this project for possible future design assistance.

As illustrated in the following three graphs the building has a pronounced effect of the soil temperatures at various depths. The winter temperatures are much warmer under the building, while in the summer the opposite is true.

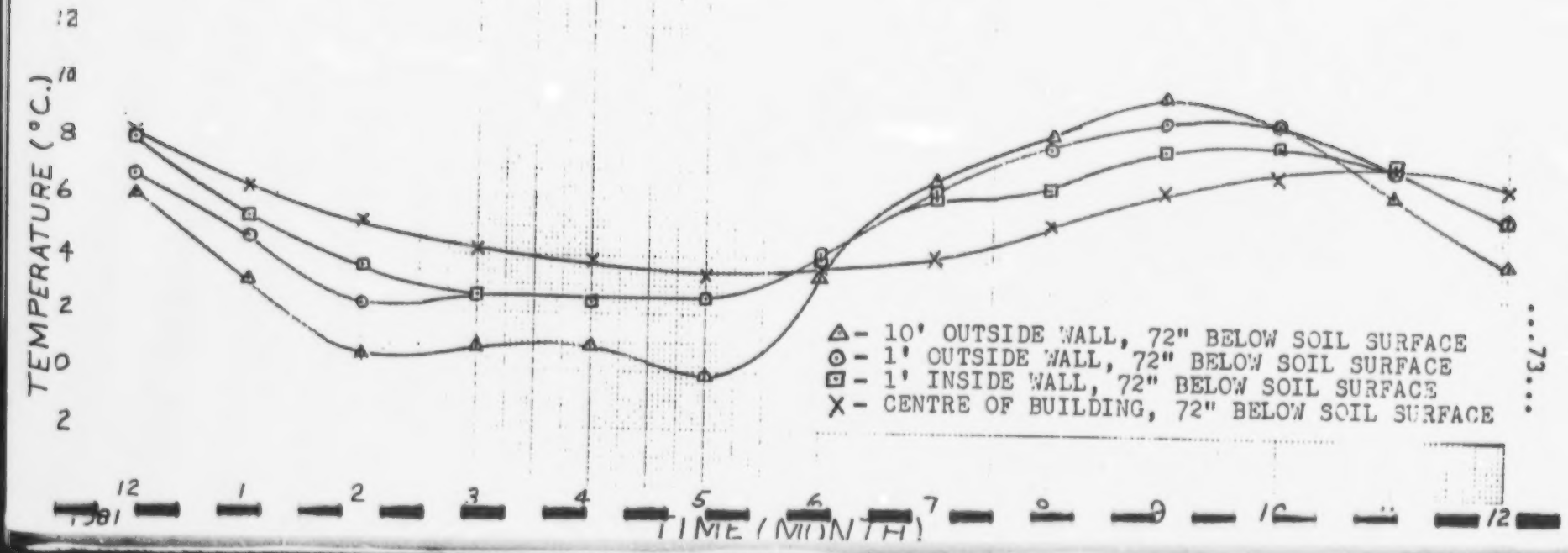

TEMPERATURE VS TIME(1st DAY OF MONTH)
TEMPERATURE (°C.)
16
14
12
10
8
6
4
2
0
-2
-4
-6
12
1
2
3
4
5
6
7
8
9
10
11
12
TIME (MONTH)
O- 1' OUTSIDE WALL, 2' BELOW INSULATION
□- 1' INSIDE WALL, 2" BELOW SOIL SURFACE
X- CENTRE OF BUILDING, 2" BELOW SOIL SURFACE

TEMPERATURE VS TIME(1st DAY OF MONTH)



...72...

TEMPERATURE VS TIME(1st DAY OF MONTH)



15. MONITORING RESULTS AND CONCLUSIONS Cont.

(q) Unheated Garage Temperatures - Data Page B-45

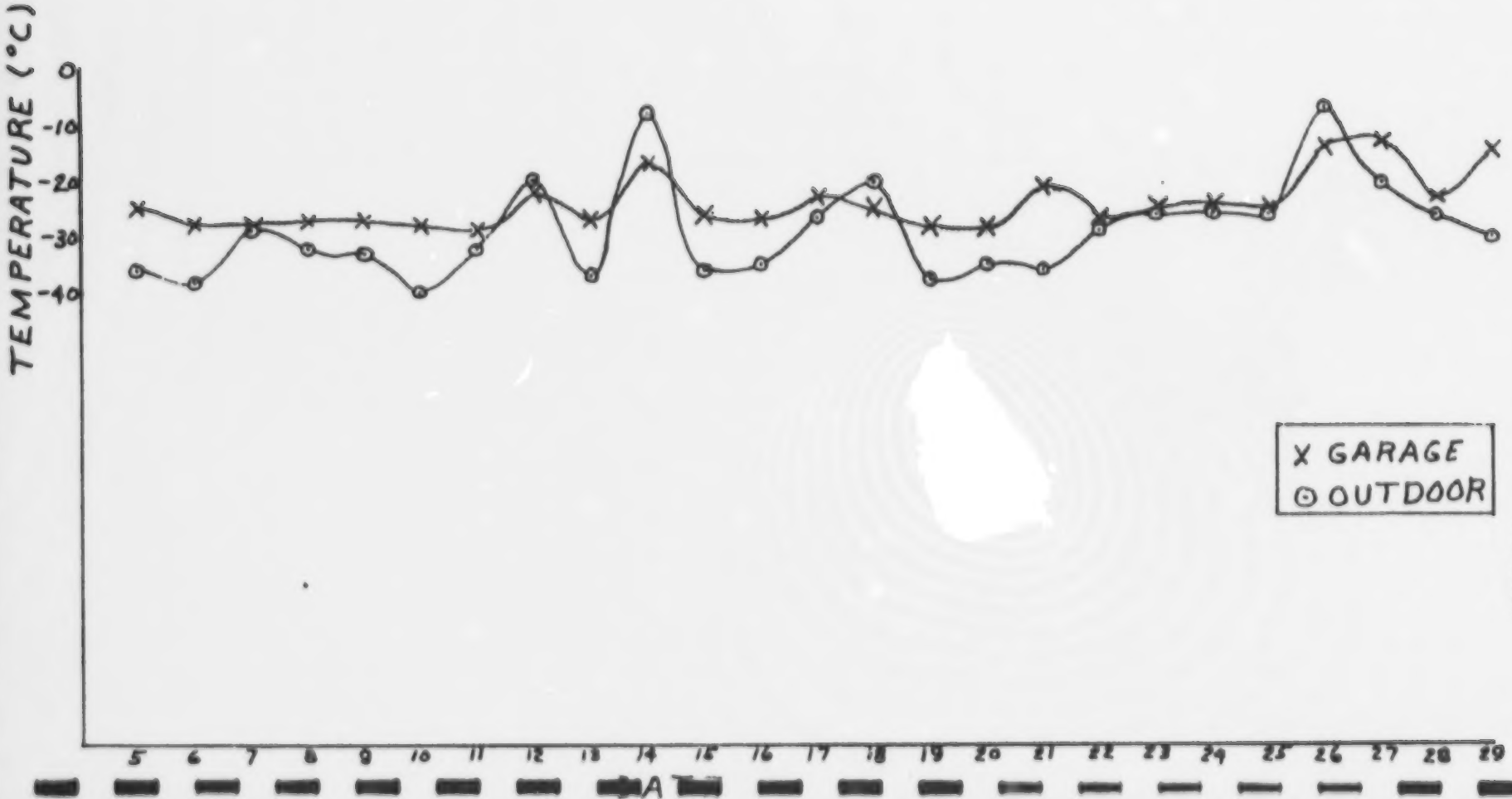
As illustrated in the following graph an unheated garage does offer a significant temperature improvement for car storage. The average temperature difference is 4.52°C. if all days are included and 6.48°C. if only the days on which the garage temperature was higher are included.

(r) Payback Periods

The payback periods for wall and ceiling insulation are as shown in Table 10 and 11 and are self-explanatory. The payback periods for the features of the test building are shown in Table 12. As indicated all of the features have reasonable payback periods since the building is on a commercial electric rate, and uses electric back-up heat. If natural gas had been used it is apparent that the payback periods would be excessive.

GARAGE & OUTDOOR TEMPERATURES

JAN. 1982, 8:30



16. RECOMMENDATIONS FOR WORKSHOP OR DWELLING CONSTRUCTION

(a) Insulation

Levels - The payback periods increase as the level of insulation increases as illustrated in Table 10 and Table 11. The exact level which is most practical for a given situation will depend on many factors, however, the following figures suggest a suitable range for consideration:

Walls - R 30 to R 45
Ceilings - R 40 to R 60

Basement insulation should be at least R 30 from 1 ft. below grade to the main floor, and at least R 20 from 1 ft. below grade to the basement floor. A basement floor should have R 10 to R 15 insulation either above it or below it. If the floor is concrete and is to be used as a heat sink, as in the building covered by this report, then the R value should be R 15 to R 20 below the floor.

A concrete floor on grade has a very high perimeter heat loss as illustrated in Table 6. In the building covered by this report the perimeter heat loss would have been equal to the total of all other heat losses from the building, had the edge of the concrete been exposed directly to the outside air. Perimeter insulation for a concrete floor on grade should be a minimum of R 10 and should extend at least 18" below grade to reduce the theat loss from the soil near the edge of the building. Using extruded polystyrene 2" thick by 24" wide and placing it at a 45 angle has worked well on this test building. The edge of the concrete floor was poured with a 45° slope to provide a tight fit against the insulation.

Types - Each type has its own advantages and disadvantages based on ease of application, cost per R unit, and durability. The types which appear to be questionable from a cost per R unit consideration are expanded vermiculite, expanded & extruded polyetyrene and urea formaldehyde foam. Blown fibreglas or blown cellulose fibre can usually be used in place of vermiculite. Some contractors express concern regarding the permenancy of the fire rating of cellulose fibre. Mineral wool or fibreglas batts can usually be used in place of either expanded or extruded polystyrene, except under a concrete floor where extruded polystyrene is the only suitable material. The use of either expanded or extruded polystyrene as an exterior sheathing either in place of plywood, or in addition to plywood, appears to be questionable from an overall cost consideration. A more suitable cost-wise arrangement would be 2 x 6 studding filled with fibreglas batts, sheathed on the outside with plywood and siding. The vapour barrier can then be applied to the inner surface of the 2 x 6 studding. Actual 1½" x 2½" or 1½" x 3" can then be applied to the inside of the studding, and the wiring placed in this region. The wiring space would then be filled with batts for a total R value of 30 to 32. The vapour barrier is thus approximately 1/3 of the way from the inner wall surface which will prevent any moisture condensation within the wall cavity. The vapour barrier

RECOMMENDATIONS FOR WORKSHOP OR DWELLING CONSTRUCTION

(a) Insulation cont.

is thus continuous and not penetrated by the wiring except for the service entrance.

The ceiling can be constructed in a manner similar to the walls, with 1½" x 2½" or 1½" x 3" added after the vapour barrier is in place. Batts would then be placed in this region after wiring is complete. The space between rafters can be fitted with batts, and additional blown fibreglas or cellulose fibre applied above the batts for a good seal around rafter braces.

The use of urea formaldehyde foam is now questionable from a health safety point of view.

(b) Vapour Barriers

Six mill polyethylene is preferable to 2 mill or 4 mill because of its extra strength. The extra strength reduces the risk of puncture during construction. All joints should overlap and be calked with accoustical sealant. It is important that the calked joints occur in an area where there is backing support so that the sealant will be well squeezed when the interior wall finishing material is applied. The barrier should be well attached mechanically at all window and door openings and calked with accoustical sealant. There is some question regarding the location of vapour barriers for basement walls and floors. The portion of the basement wall above grade should have its barrier on the inside of the wall, or at least not more than one third of the way from the inside of the wall. Below grade walls and basement floors present a somewhat difficult problem. The moisture level at the outside of the wall or at the lower surface of the floor may be very high, depending on soil conditions and water table levels. Thus if a wood frame floor is constructed on top of a concrete floor, and a vapour barrier is placed on the upper joist surface, the wood may become very damp, leading to wood rot. If the barrier is placed below the floor joists then there is a possibility of moisture condensation on the barrier in high humidity, winter, conditions. Some building contractors are laying a vapour barrier before pouring the concrete. It is difficult to prevent such a barrier from being damaged during the pouring of the concrete. It is recommended that the latest research and construction techniques be investigated before a decision is made regarding vapour barriers below grade.

(c) Humidity Control

In recently constructed dwellings, where great attention has been given to the placement of the vapour barrier, humidity control will be necessary. Control may not be necessary in similarly constructed buildings for other uses since moisture generation is usually lower in uses other than dwellings.

RECOMMENDATIONS FOR WORKSHOP OR DWELLING CONSTRUCTION CONT.

(c) Humidity Control cont.

The only efficient method of humidity control is by the use of an air to air heat exchanger. There are however air to air heat exchangers which are of low efficiency. There are also some heat exchangers which will help control air odors but will not be effective in reducing humidity levels.

Any reasonably efficient air to air heat exchanger which is effective in reducing the humidity level will frost up in prairie winter conditions. If it does not frost up then the unit is either low in efficiency or is not effective in reducing humidity. Since any unit doing an efficient job will frost up it is important that there be an easy, efficient method of removing the frost. The frost removal should be automatic and must be energy efficient. If all of the frost is melted by the use of either electric power, or heat from the warm air, then the overall efficiency of the heat exchanger will be reduced.

Before purchasing an air to air heat exchanger it is wise to get complete details on its operation including efficiency, moisture removal capability, defrost method, impartial test results, guarantee as to effectiveness, and references to present users in your area.

(d) Windows

Windows represent areas of high heat loss unless they are equipped with well sealed shutters. Shutters should be at least R 15 and should definitely be on the outside to prevent window frost in prairie winter conditions. The use of three glaze windows does offer some advantage over two glaze, but without shutters they are still a high energy loss region compared to the wall in which they are mounted.

The number of windows used should be kept to an absolute minimum, other than south or east facing shutter equipped windows used as solar collectors.

The larger air spaces used in the windows of this test building did result in larger R values, however, without shutters they were still of very low R value compared to the wall in which they were located. The labor and material going into the shutters offered a greater saving than the extra labor and materials going into the extra glazing.

The shutters used on this test building are manually controlled. There is a tendency to leave the shutters in the closed position because of the bother to open them. The shutters were left closed for the entire 1982-83 heating season. This season was extremely cloudy, however there were some sunny days near the end of the season during which the shutters should have been open. The development of a low cost, dependable, remote operating system would enhance the desirability of outside shutters.

RECOMMENDATIONS FOR WORKSHOP OR DWELLING CONSTRUCTION

(e) Solar Heating

The energy actually obtained from solar heating was considerably less than that anticipated. Considering the long payback periods it would appear that high insulation levels and air infiltration reduction should be achieved before solar heating is considered. Even with forseeable technical improvements which could increase efficiency and reduce the cost of solar collectors the payback periods will be relatively long. There is however a certain feeling of satisfaction associated with being in a building in which "free" heat is being supplied by the sun.

If solar collectors are desired the type as used in the vertical south and east walls would be recommended. This type uses two collectors with one common air fan, and one common air outlet, both equipped with automatic dampers. The construction cost is relatively low, night heat retention is good, servicing is convenient, and the outer glazing is easy to clean. Collectors must be shaded to keep summertime temperatures within the collectors at reasonable values. If windows are used as solar collectors, they must also be protected from the summer sun to prevent overheating of the building. This would be best done by use of outside shutters which provide summer shade and also reduced night-time heat loss.